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# Computer Economics of Physical Coal Cleaning and Flue Gas Desulfurization
Final Report

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# Computer Economics of Physical Coal Cleaning and Flue Gas Desulfurization —

Final Report

by

C.R. Wright, L. Larkin, F.M. Kennedy, and T.W.Tarkington

TVA, Power and Engineering
Division of Energy Demonstrations and Technology
Muscle Shoals, Alabama 35661

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EPA Project Officer: James D. Kilgroe
Air and Energy Engineering Research Laboratory
Office of Environmental Engineering and Technology
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16. ABSTRACT

The report describes a computer model developed by TVA to simulate the performance and determine the economics of coal cleaning, or coal cleaning combined with flue gas desulfurization (FGD), for power plant emission control processes over a wide range of user-specified conditions. The model also calculates the other economic benefits and penalties to overall power plant operation that result from the use of cleaned coal. The report describes: (1) the programs composing the model, (2) the design and economic premises on which the calculations performed by the model are based, (3) the designs for the coal-cleaning and the FGD processes, and (4) the economic benefits and penalties associated with the use of cleaned coal by a power plant. A variety of cases were simulated, and selected results from these runs are described. For the cases studied, the use of coal cleaning in combination with FGD had a varied effect on the levelized annual cost of power production. This effect, which depends on the coal and the specific operating conditions, ranges from a 0.5% increase to a 22.6% decrease in those costs. The methods used to determine many of the other economic benefits and penalties of coal cleaning are necessarily general in nature because detailed data relating specific coal properties to boiler performance and operating costs are scarce.

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| Economics | | Stationary Sources | 05C | |
| Mathematical Models | | Physical Coal Cleaning | 12A | |
| Coal Preparation | | Coal Cleaning | 08I | |
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# ABSTRACT

A computer model was developed by the Tennessee Valley Authority (TVA) to simulate the performance and determine the economics of coal cleaning, or coal cleaning combined with flue gas desulfurization (FGD), for power plant emission control processes over a wide range of user-specified conditions. The model also calculates the other economic benefits and penalties to overall power plant operation that result from the use of cleaned coal. This report describes (1) the programs composing the model, (2) the design and economic premises on which the calculations performed by the model are based, (3) the designs for the coal-cleaning and the FGD processes, and (4) the economic benefits and penalties associated with the use of cleaned coal by a power plant. To illustrate the use of the model, a variety of cases were simulated and selected results from these runs are described.

For the cases studied, it was found that the use of coal cleaning in combination with FGD can have a varied effect on the levelized annual cost of power production. This effect, which is dependent on the coal and the specific operating conditions, ranges from a 0.5% increase to a 22.6% decrease in those costs.

The methods used to determine many of the other economic benefits and penalties of coal cleaning are necessarily general in nature because detailed data relating specific coal properties to boiler performance and operating costs are scarce. Thus, development and incorporation of more detailed and quantitative data in the model would greatly increase the usefulness of the model in assessing overall economic effects of coal cleaning.

# CONTENTS

Abstract . . . . . . . . . . . . . . . . . . . . . . . . . . iv
Figures . . . . . . . . . . . . . . . . . . . . . . . . . . vii
Tables . . . . . . . . . . . . . . . . . . . . . . . . . . viii
Abbreviations and Conversion Factors . . . . . . . . . . . . . . x

Executive Summary . . . . . . . . . . . . . . . . . . . . . . S-1

Introduction . . . . . . . . . . . . . . . . . . . . . . . . . 1

Model Description . . . . . . . . . . . . . . . . . . . . . . 5
  Model Input Procedure . . . . . . . . . . . . . . . . . . . 5
  Coal-Cleaning Program . . . . . . . . . . . . . . . . . . . 7
    Coal-Cleaning Program Inputs . . . . . . . . . . . . . . . 8
    Coal-Cleaning Program Printout . . . . . . . . . . . . . . 15
    Coal-Cleaning Process . . . . . . . . . . . . . . . . . . 18
  FGD Program . . . . . . . . . . . . . . . . . . . . . . . . 22
    FGD Process . . . . . . . . . . . . . . . . . . . . . . . 23
  Economic Benefits and Penalties Program . . . . . . . . . . 25

Design and Economic Premises for Model Use . . . . . . . . . . 45
  Study Design Premises . . . . . . . . . . . . . . . . . . . 45
    Coal Premises . . . . . . . . . . . . . . . . . . . . . . 45
    Coal-Cleaning Plant . . . . . . . . . . . . . . . . . . . 46
    Power Plant Design . . . . . . . . . . . . . . . . . . . . 47
    Emission Standards . . . . . . . . . . . . . . . . . . . . 47
    FGD System . . . . . . . . . . . . . . . . . . . . . . . . 47
  Economic Premises . . . . . . . . . . . . . . . . . . . . . 48
    Capital Investment . . . . . . . . . . . . . . . . . . . . 48
    Annual Revenue Requirements . . . . . . . . . . . . . . . 51

Results and Illustrative Examples of Model Use . . . . . . . . 55
  Operating Performance . . . . . . . . . . . . . . . . . . . 59
    Coal Cleaning Performance . . . . . . . . . . . . . . . . 60
    FGD Performance . . . . . . . . . . . . . . . . . . . . . 63
    Combined Coal Cleaning and FGD . . . . . . . . . . . . . . 64
  Economics . . . . . . . . . . . . . . . . . . . . . . . . . 64
    Capital Investment . . . . . . . . . . . . . . . . . . . . 64
    Annual Revenue Requirements . . . . . . . . . . . . . . . 67
    Case Variations and Sensitivities . . . . . . . . . . . . 72

Project Conclusions and Recommendations . . . . . . . . . . . 77

References . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 79

Appendix . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 83

Coal Washability Data . . . . . . . . . . . . . . . . . . . . . 84
Example Input for Base Case (Long Form) . . . . . . . . . . . 91
Example Input for Base Case (Short Form) . . . . . . . . . . . 98
Example Printout for Base Case . . . . . . . . . . . . . . . . 100
Summary of Coal-Cleaning and FGD Performance Data . . . . . . . . 138
Summary of Coal-Cleaning and FGD Economic Data . . . . . . . . . . 140

EPA Form 2350-4 (4-80)
(PREVIOUSLY DIN. EPA FORM 247)

# FIGURES

**Number** **Page**

S-1 Flow of data through the combined model . . . . . . . . . . . . S-3
S-2 Flow diagram for the coal-cleaning process . . . . . . . . . . S-4
S-3 Flow diagram for the limestone-scrubbing FGD process . . . . . S-6
S-4 Effect of Btu recovery on the net total capital investment, Pittsburgh coal at 1.20 emission limit . . . . . . . . . . . . S-13
S-5 Effect of Btu recovery on the net levelized annual revenue requirements, Pittsburgh coal at 1.20 emission limit . . . . . S-14
S-6 Effect of emission limit on the power generation cost reduction attributable to coal cleaning (at optimum specific gravity) . . . . . . . . . . . . . . . . . . . . . . . . . S-16

1 Flow of data through the combined model . . . . . . . . . . . . 6
2 Distribution curve for the dense-medium vessel (3 in. x 3/8 in. coal) . . . . . . . . . . . . . . . . . . . . . . . . . . 11
3 Flow diagram for the coal-cleaning process . . . . . . . . . . 19
4 Flow diagram for the limestone-scrubbing process . . . . . . . 24
5 The effect of specific gravity of separation on Btu recovery . . . . . . . . . . . . . . . . . . . . . . . . . . 61
6 Effect of Btu recovery on the actual $SO_2$ emission levels . . . 62
7 Effect of the emission limit on the flue gas bypassed when burning the four premise coals (FGD alone with no coal cleaning . . . . . . . . . . . . . . . . . . . . . . . . 65
8 Effect of Btu recovery on the flue gas bypassed at the 1.20 lb $SO_2$/MBtu emission limit) . . . . . . . . . . . . . . . . . 66
9 Btu recovery versus net capital investment for coal cleaning, Illinois No. 6 coal . . . . . . . . . . . . . . . . . . . . 68
10 Btu recovery versus net capital investment for coal cleaning, Pittsburgh coal . . . . . . . . . . . . . . . . . . . . . . 68
11 Effect of Btu recovery on the net total capital investment for a coal-cleaning process, including all benefits and penalties, Pittsburgh coal at 1.20 emission limit . . . . . . . . . . . . 69
12 Btu recovery versus net levelized annual revenue requirements, Illinois No. 6 coal . . . . . . . . . . . . . . . . . . . . 70
13 Btu recovery versus net levelized annual revenue requirements, Pittsburgh coal . . . . . . . . . . . . . . . . . . . . . . 71
14 Effect of Btu recovery on the components of net levelized annual revenue requirements for the combined process, Pittsburgh coal at the 1.20 lb $SO_2$/MBtu emission limit . . . . 73
15 Effect of emission limit on the power generation cost reduction attributable to coal cleaning (at optimum specific gravity) . . . . . . . . . . . . . . . . . . . . . . . . . 76

EPA Form 2200-4 (4-80)

## TABLES

**Number** **Page**

S-1 Selected Characteristics and Equivalent $SO_2$ Contents of the Premise Coals . . . . . . . . . . . . . . . . . . . . . . . . S-9
S-2 Sulfur Reduction and Btu Recovery by Coal Cleaning . . . . . S-11

1 Unit Operations Simulated by the Coal-Cleaning Program and the Input Data Required . . . . . . . . . . . . . . . . . . 9
2 Washability Data for the Pittsburgh Coal . . . . . . . . . . 13
3 Acceptable Equation Forms for Determining the Process Area Investment . . . . . . . . . . . . . . . . . . . . . . . . . 16
4 State-Imposed Coal Taxes as of September 30, 1980 . . . . . . 30
5 Compositions of Premise Coals, As-Received Basis . . . . . . 46
6 Cost Indexes . . . . . . . . . . . . . . . . . . . . . . . 49
7 Variables Used in Determining Coal-Cleaning Area Investment . 50
8 Percentage Factors for Proportioned Investments . . . . . . . 51
9 Projected 1984 Unit Costs for Raw Materials, Labor, and Utilities . . . . . . . . . . . . . . . . . . . . . . . . . 52
10 Variables Used in Determining Coal-Cleaning Process Direct Costs . . . . . . . . . . . . . . . . . . . . . . . . . . 52
11 Levelized Annual Capital Charges for Regulated Utility Financing . . . . . . . . . . . . . . . . . . . . . . . . . 53
12 Conditions Evaluated . . . . . . . . . . . . . . . . . . . 56
13 Sulfur Reduction and Btu Recovery by Coal Cleaning . . . . . 63
14 Net Total Capital Investment and Levelized Annual Revenue Requirements for Various Power Plant Sizes . . . . . . . . . . 74
15 Net Levelized Annual Revenue Requirements at Various Transportation Distances . . . . . . . . . . . . . . . . . . 75

A-1 Washability Data for the Pittsburgh Coal . . . . . . . . . . 84
A-2 Washability Data for the Illinois No. 6 Coal . . . . . . . . 86
A-3 Washability Data for the Upper Freeport Coal . . . . . . . . 88
A-4 Washability Data for the Cedar Grove Coal . . . . . . . . . . 90
A-5 Example Input Data for the Base Case (Long Form) . . . . . . 91
A-6 Example Input Data for the Base Case (Short Form) . . . . . . 98
A-7 Example Printout for the Base Case . . . . . . . . . . . . . 100
A-8 Summary of Coal-Cleaning Performance Data and Changes in FGD Performance Data as a Result of Coal Cleaning . . . . . 138

## TABLES (Continued)

**Number** **Page**

A-9 Summary of Total Capital Investment for Coal-Cleaning, FGD, and Economic Benefits . . . . . . . . . . . . . . . . . . . . 140

A-10 Summary of Annual Revenue Requirements for Coal-Cleaning, FGD, and Economic Benefits . . . . . . . . . . . . . . . . . . . . 142

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## ABBREVIATIONS AND CONVERSION FACTORS

### ABBREVIATIONS

| | |
|---|---|
| CCC | Chemical coal cleaning |
| DM | Dense medium |
| EPA | Environmental Protection Agency |
| ESP | Electrostatic precipitator |
| FD | Forced draft |
| FGD | Flue gas desulfurization |
| G | Billion or giga |
| ID | Induced draft |
| k | Thousand or kilo |
| M | Million or mega |
| NSPS | New source performance standards |
| PCC | Physical coal cleaning |
| ROM | Run of Mine |
| SIP | State Implementation Plan |
| TVA | Tennessee Valley Authority |

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# CONVERSION FACTORS

EPA policy is to express all measurements in Agency documents in metric units. Values in this report are given in British units for the convenience of engineers and other scientists accustomed to using the British systems. The following conversion factors may be used to provide metric equivalents.

| To convert British | | Multiply by | To obtain Metric | |
|---|---|---|---|---|
| ac-ft | acre-foot | 1.234 | cubic meter | $m^3$ |
| Btu | British thermal unit | 1.055 | joule or Newton-meter | J or N·m |
| Btu/lb | British thermal unit per pound | 2.326 | kilojoules per kilogram | kJ/kg |
| $ft^3$ | cubic feet | 0.028 | cubic meter | $m^3$ |
| $ft^3/min$ | cubic feet per minute | 0.0004719 | cubic meter per second | $m^3/s$ |
| ft | foot | 0.3048 | meter | m |
| ft/min | foot per minute | 0.00508 | meter per second | m/s |
| gal | gallon (U.S.) | 3.785 | liter | |
| gal/min | gallon (U.S.) per minute | 0.063 | liter per second | /s |
| hp | horsepower | 0.746 | kilowatt or kilojoule per second | kW, kJ/s |
| mi | mile | 1.61 | kilometer | km |
| lb | pound | 0.454 | kilogram | kg |
| $lb/ft^2$ | pound per square foot | 47.88 | pascal | Pa |
| $lb/ft^3$ | pound per cubic foot | 16.018 | kilogram per cubic meter | $kg/m^3$ |
| $lb/in^2$ | pound per square inch | 6.894 | kilopascal | kPa |
| lb/MBtu | pound per million Btu | 429.9 | nanograms per joule | ng/J |
| ton[a] | ton (2,000 lb) | 0.907 | megagrams | mg |
| ton/hr | ton per hour | 0.252 | kilogram per second | kg/s |

a. All tons, including tons of sulfur, are expressed in short tons (2,000 lb) in this report.

Note: Metric units are those of the SI (Systeme International) metric system.

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# COMPUTER ECONOMICS OF PHYSICAL COAL CLEANING AND FLUE GAS DESULFURIZATION

## EXECUTIVE SUMMARY

### INTRODUCTION

During the past 15 years, the Tennessee Valley Authority (TVA) has performed many economic evaluations of power plant flue gas desulfurization (FGD) and other air pollution control processes. In some instances, these evaluations have supplied the technical background information for detailed computer programs that simulate the operation of selected processes. In recent years, coal cleaning, sometimes used in conjunction with FGD, has come to be regarded as a practical alternative for the control of $SO_2$ emissions from coal-fired power plants. TVA recently completed an economic evaluation for the U.S. Environmental Protection Agency (EPA) that demonstrated the potential of coal cleaning in $SO_2$ emission control. As a continuation of this program, a computer model was developed to model the performance and economics of full-scale coal cleaning and limestone and lime FGD.

This report provides a general description of the model and illustrations of its use. A more detailed description of the data needed to run this computer model is contained in the users manual, which has also been prepared by TVA. The model determines the process design and economics for a coal-cleaning process or a coal-cleaning process combined with FGD as a pollution control system. It also determines the economic benefits and penalties attributable to the use of cleaned coal instead of raw coal.

The results obtainable from the combined model should be useful in comparisons of the process designs and economics of various combinations of physical coal-cleaning and lime or limestone FGD processes. This should be particularly useful when evaluating processes for specific applications since the model will illustrate the effect of changes in process variables on the cost and design of the component processes and the entire system.

### MODEL DESCRIPTION

The combined coal-cleaning - FGD computer model consists of four separate computer programs (written in FORTRAN IV), which are linked by common input and output data. The first program determines process performance and economics of the coal-cleaning plant from design and operating specifications. The second program determines the FGD process design, operating conditions,

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(PREVIOUSLY CIN. EPA FORM 287)

and the corresponding capital investment from the coal properties and emission requirements. The third program uses the design data determined in the second program to calculate the annual revenue requirements for the FGD process. The fourth program quantifies selected economic benefits and penalties of using cleaned coal. Unlike the first three programs, which are modified versions of previously developed programs, the fourth program was created specifically for this project.

## Model Input Procedure

In order to simplify data entry for the four programs comprising this model, all data required for the simulation are included as input data to the coal-cleaning program. The information required includes power plant data, emission regulations, coal-cleaning process specifications, FGD design specifications, raw coal properties and washability, and economic data. The flow of the data throughout the combined model is shown in Figure S-1.

## Coal-Cleaning Program

The coal-cleaning program was adapted from a program developed by Battelle Columbus Laboratories from earlier models as the Coal Preparation Simulation Model (CPSM4), Version 2. The Battelle version, which actually originated at the University of Pittsburgh, was obtained from Versar, Inc., who also provided valuable assistance in its adaptation to the TVA computer system. The program required many modifications to conform to the TVA process design criteria and to form the combined coal-cleaning - FGD model. Many of these changes were relatively minor and did not alter the program processing sequence but some areas required major revisions, thereby necessitating the addition of five new subroutines and the associated rearrangement of the program.

The output of this program is divided into three segments. The first segment lists the values of selected input data to ensure that no errors were made during the input operation. The second, or execution segment, provides an analysis of internal flow streams and a performance report for each equipment unit included in the coal-cleaning process. The third segment presents the overall results of the simulation. The tables included in this segment provide the performance data and the process economics for the coal-cleaning plant.

The model is capable of simulating many coal-cleaning processes provided that equipment performance, process design information, and economic data are available. The base case process design used for the illustrative runs in this report is shown in Figure S-2. The process, as illustrated, separates the raw coal into three size fractions, each of which is processed in a different type of separation equipment. The coarse coal is cleaned in a dense-medium vessel, the intermediate coal in a dense-medium cyclone, and the fine coal in froth flotation cells.

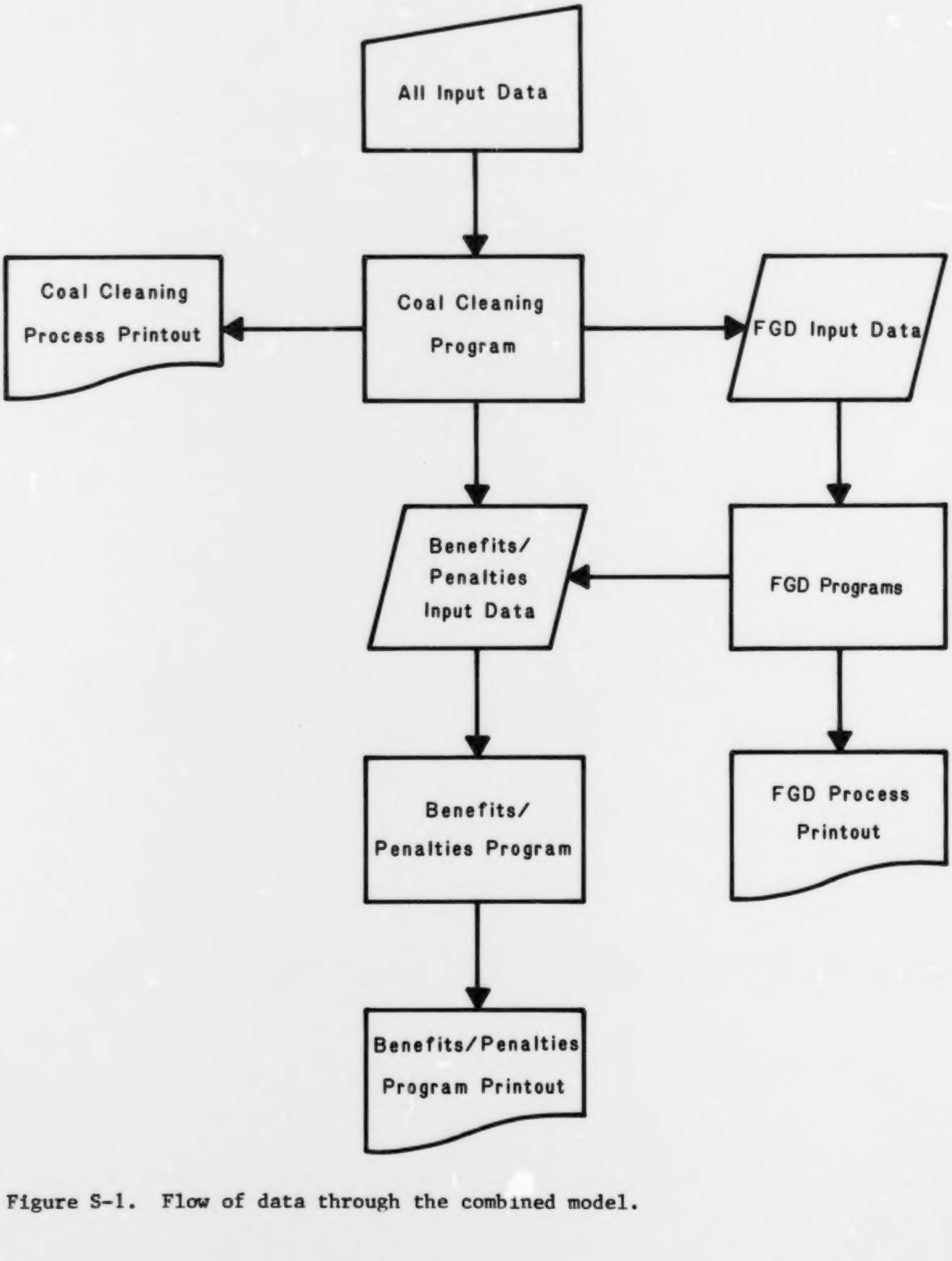
All Input Data
Coal Cleaning Process Printout
Coal Cleaning Program
FGD Input Data
Benefits/ Penalties Input Data
FGD Programs
Benefits/ Penalties Program
FGD Process Printout
Benefits/Penalties Program Printout

Figure S-1. Flow of data through the combined model.

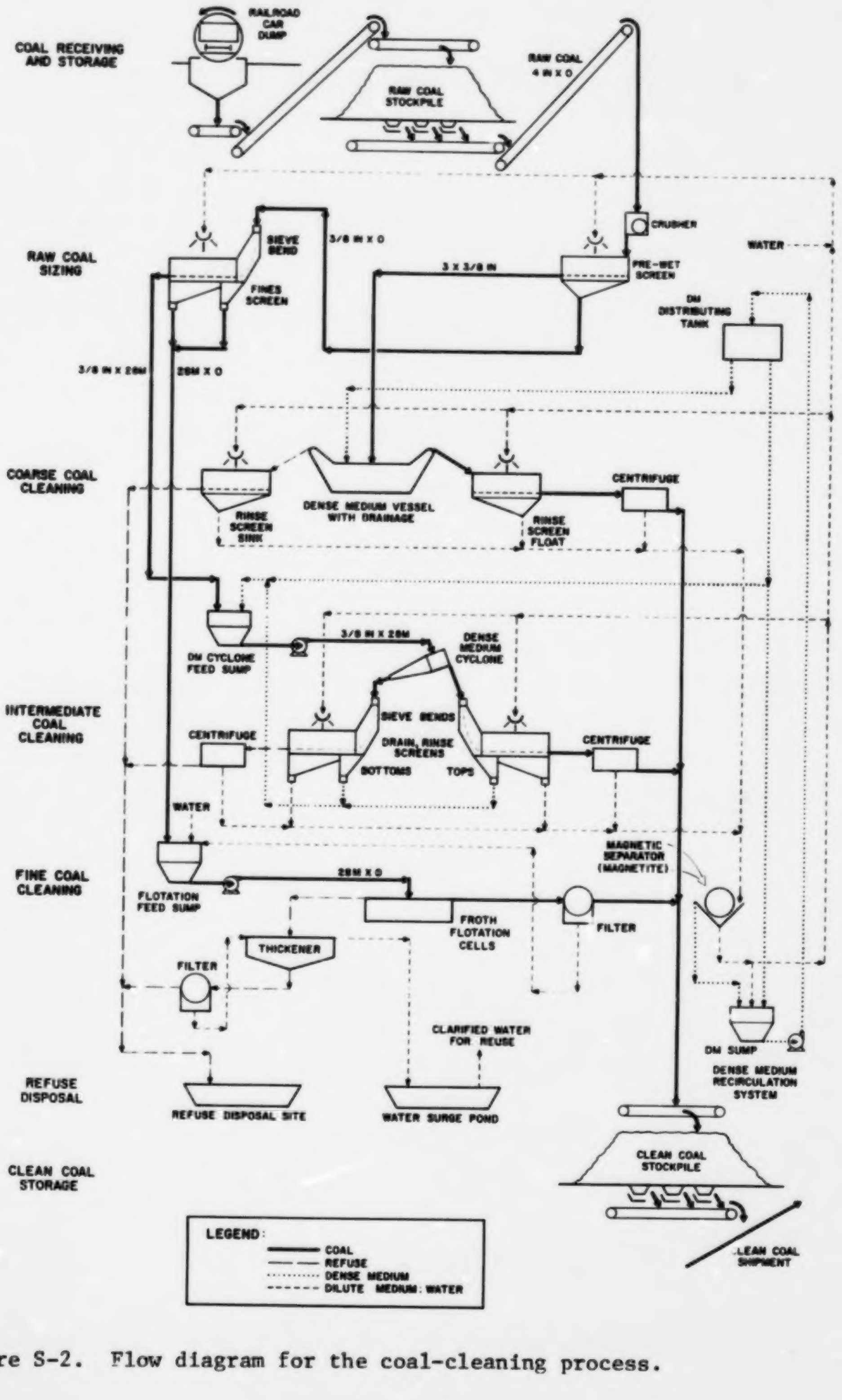
COAL RECEIVING AND STORAGE
RAILROAD CAR DUMP
RAW COAL STOCKPILE
RAW COAL 4 IN X 0
RAW COAL SIZING
SIEVE BEND
3/8 IN X 0
CRUSHER
WATER
3 X 3/8 IN
PRE-WET SCREEN
FINES SCREEN
DM DISTRIBUTING TANK
3/8 IN X 28M
28M X 0
COARSE COAL CLEANING
DENSE MEDIUM VESSEL WITH DRAINAGE
RINSE SCREEN SINK
RINSE SCREEN FLOAT
CENTRIFUGE
3/8 IN X 28M
DENSE MEDIUM CYCLONE
DM CYCLONE FEED SUMP
INTERMEDIATE COAL CLEANING
SIEVE BENDS
CENTRIFUGE
DRAIN, RINSE SCREENS
BOTTOMS
TOPS
CENTRIFUGE
WATER
MAGNETIC SEPARATOR (MAGNETITE)
FINE COAL CLEANING
28M X 0
FLOTATION FEED SUMP
FROTH FLOTATION CELLS
FILTER
THICKENER
FILTER
CLARIFIED WATER FOR REUSE
DM SUMP
DENSE MEDIUM RECIRCULATION SYSTEM
REFUSE DISPOSAL
REFUSE DISPOSAL SITE
WATER SURGE POND
CLEAN COAL STORAGE
CLEAN COAL STOCKPILE
CLEAN COAL SHIPMENT
LEGEND:
COAL
REFUSE
DENSE MEDIUM
DILUTE MEDIUM: WATER

Figure S-2. Flow diagram for the coal-cleaning process.

## FGD Model

The FGD model is the Shawnee lime/limestone computer model developed by Bechtel National, Inc., and TVA using data obtained from the EPA-sponsored test facility at the TVA Shawnee Steam Plant near Paducah, Kentucky. This model consists of two programs that, when executed in the appropriate sequence, produce full-scale design and economic data for a variety of limestone or lime FGD systems.

The FGD model has been revised many times since its inception in the mid-1970s to update design and economic data and add new process options. The current version includes options for limestone or lime scrubbing; mobile-bed, spray tower, or venturi absorbers; and various waste disposal methods. The flow diagram for the FGD process design used to illustrate the capabilities of the combined model is shown in Figure S-3. The process employs limestone slurry scrubbing in a spray tower absorber and the untreated waste is disposed of in a pond.

## Economic Benefits and Penalties Program

There are many differences between cleaned coal and raw coal that result in economic benefits and penalties for a power plant other than the obvious benefit of reduced emission control costs. This program utilizes appropriate equations to approximate many of these benefits and penalties that accrue because of such differences as lower ash content, higher moisture content, and generally higher heating value of the cleaned coal. Each of the benefits and penalties calculated by this program is discussed below.

### FGD Costs--

The most important effect of coal cleaning on power plant costs is in the area of FGD costs. The primary use of this model is to illustrate potential cases where coal cleaning or coal cleaning with FGD is more economical than FGD alone in controlling $SO_2$ emissions. The reduced sulfur content and increased heat content of cleaned coal reduce the quantity of $SO_2$ produced in the combustion process, thus reducing the $SO_2$ removal requirement of the FGD process. In some cases, the use of cleaned coal can even eliminate the need for FGD. The FGD cost benefit is determined by comparing FGD costs when controlling raw coal combustion emissions with FGD costs when controlling cleaned coal combustion emissions.

### Raw Coal Loss--

No presently available coal-cleaning process is capable of achieving 100% separation of pure coal from its impurities. As a result, there is some coal lost in the cleaning plant refuse and some impurities remain in the cleaned coal. The coal that is lost creates an economic liability for the coal-cleaning plant. This liability or penalty is quantified for this model based on the heat content (Btu's) of the coal that is lost in the refuse.

### Transportation Costs--

In most cases, coal cleaning produces a product that has a higher heating value than the raw coal, thereby reducing the quantity of coal

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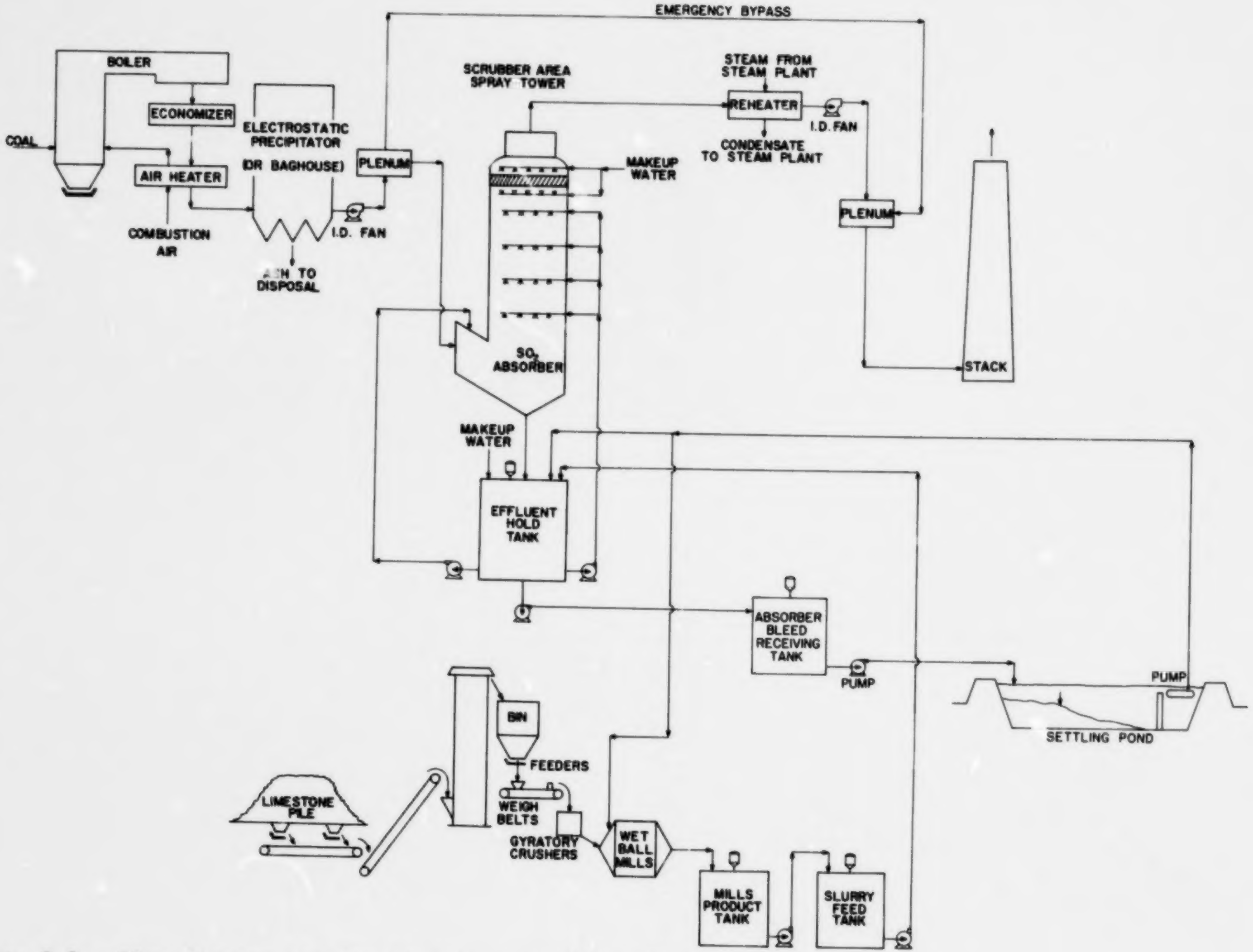
EMERGENCY BYPASS
BOILER
COAL
ECONOMIZER
AIR HEATER
COMBUSTION AIR
ELECTROSTATIC PRECIPITATOR (OR BAGHOUSE)
ASH TO DISPOSAL
I.D. FAN
PLENUM
SCRUBBER AREA SPRAY TOWER
MAKEUP WATER
SO2 ABSORBER
STEAM FROM STEAM PLANT
REHEATER
CONDENSATE TO STEAM PLANT
I.D. FAN
PLENUM
STACK
MAKEUP WATER
EFFLUENT HOLD TANK
ABSORBER BLEED RECEIVING TANK
PUMP
PUMP
SETTLING POND
BIN
FEEDERS
LIMESTONE PILE
WEIGH BELTS
GYRATORY CRUSHERS
WET BALL MILLS
MILLS PRODUCT TANK
SLURRY FEED TANK

Figure S-3. Flow diagram for the limestone-scrubbing FGD process.

necessary to satisfy the heat requirements of a specific power plant. When coal cleaning is performed at the mine, the reduced coal requirement decreases the cost of transporting the coal, which is a cost benefit for the utility.

United Mine Workers' Benefits--

The provisions of the 1978 United Mine Workers' (UMW) contract require mine operators to pay $1.385 to the Pensions and Benefit Trust Fund for every ton of coal shipped to a consumer. Since coal cleaning generally reduces the quantity of coal required by a power plant, the contribution to the trust fund is also reduced, thereby resulting in a cost benefit for the utility.

State Taxes--

State-imposed coal taxes, often called severance taxes, are presently levied by the legislatures of 13 states. Depending upon the method of taxation, coal cleaning can reduce or increase these taxes, thus creating a cost benefit or penalty. At present, there are four methods of applying these charges, of which taxation based on the tonnage of coal shipped is the most common, and for this reason is used in the example runs for this project. Based on this method, coal cleaning would generally yield an economic benefit by reducing the quantity shipped. On the other hand, taxation based on the tonnage mined or value of the coal mined would produce an economic penalty for coal cleaning because of the coal loss in the cleaning plant refuse.

Size Reduction--

In general, at least two and sometimes three size reduction operations are performed on coal as it moves from the ground to the power plant boiler. For the development of this program, it was assumed that the power plant was equipped with pulverized coal boilers in which case three separate size reduction operations are necessary. The first operation is performed at the mine where the run-of-mine (ROM) coal is crushed to the appropriate topsize. The next two operations are performed at the power plant where the coal is crushed for feeding to the pulverizers and then ground into powder and fed to the boiler. In cases where coal cleaning is used, an additional size reduction operation is usually included, which results in a cost benefit to the utility because the coal crushing requirement at the power plant is reduced. Coal cleaning can also result in a benefit in the size reduction operations at the power plant by reducing the coal mineral matter, thus decreasing the hardness and making it easier to grind. Also, the increased heating value of cleaned coal decreases the amount to be ground. One effect of coal cleaning, the increase in surface moisture, can increase pulverizer plugging, but it is not considered in the program due to the lack of appropriate data.

Maintenance Costs--

The quality and quantity of the coal used in a power plant have long been recognized as having a significant effect on the maintenance costs of the plant equipment. Some of the equipment areas have been mentioned in the preceding paragraphs, but other areas which must be considered include the boilers and accessories, coal conveying and storage equipment, and the air heaters. Coal cleaning yields an economic benefit in the maintenance costs for these and other areas of power plant operation by raising the quality of coal burned in the plant through the reduction of the ash and sulfur content. To quantify this benefit, the program uses a relationship based on the ash and sulfur in the coal which is derived from actual power plant maintenance data.

### Power Plant Availability--

The availability of a power plant for the production of electricity is another area that is affected by the use of cleaned coal. Many of the factors relating to availability, such as tube corrosion, sootblower failure, slagging, and fouling are influenced by the mineral content of the coal burned; therefore, they are also influenced by the use of cleaned coal. It is difficult to quantify the effects of coal cleaning on availability because of factors unrelated to fuel quality, such as plant age, which have a masking effect. In the program, an attempt is made to quantify this effect (a benefit in all cases) through the use of a logarithmic relationship based on the coal ash and sulfur content.

### Boiler Efficiency--

The efficiency of a power plant boiler is often expressed in terms of the amount of heat required to generate one kilowatt-hour of power. This characteristic of the power plant is affected by coal cleaning in much the same manner as availability, with one notable exception. This is the negative effect that the increased moisture, inherent in cleaned coal, has on boiler efficiency. More specifically, tube fouling and slagging are generally reduced by coal cleaning, thus increasing efficiency, but the increased moisture content has an offsetting effect. One additional factor affecting efficiency, but not related to coal cleaning, is the age of the boiler. All of these factors are included in the equation used by the model to quantify this benefit (or penalty as the case may be).

### Electrostatic Precipitation--

The major factors controlling the size and cost of an electrostatic precipitator (ESP) are the specific collection area, which is determined primarily by the fly ash resistivity and volumetric flow rate of flue gas. Fly ash resistivity is related to such factors as ash content, ash composition, and sulfur content. Volumetric flow rate is related to the coal composition. Since coal cleaning alters the composition, it may either increase or decrease the volumetric flow rate of flue gas, depending on the effects of different coal components. In some cases, coal cleaning may cause a change in fly ash resistivity which results in a net increase in the ESP specific collection area. If this increase is not offset by a reduction in the volumetric flow rate of flue gas then the results of cleaning are detrimental and result in the imposition of an economic penalty.

### Ash Disposal--

The costs of transporting and disposing of the ash are decreased because coal cleaning reduces the ash content of the coal and generally increases the heating value of the coal, both of which decrease the quantity of ash to be disposed of at the power plant.

## DESIGN AND ECONOMIC PREMISES

The design and economic premises for the combined coal-cleaning - FGD model are based on premises developed by TVA for economic evaluations of power plant emission control processes. The premises for the benefits and penalties program were developed especially for this model.

The base case assumes a new, midwestern, 1,000-MW, pulverized-coal-fired power plant supplied by a coal-cleaning plant at a mine 500 miles away, with transportation by unit train. The design heat rate of the boiler is 9,200 Btu/kWh and it operates at full load for 5,500 hours a year over a 30-year life. The coal-cleaning process incorporates three cleaning streams: dense-medium vessels for coarse coal (3 inches x 3/8 inch), dense-medium cyclones for medium-sized coal (3/8 inch x 28 mesh), and froth flotation for fine coal (less than 28 mesh).

The cases studied are based on four coals, selected characteristics of which are presented in Table S-1 with the equivalent $SO_2$ content. Each of these coals is cleaned by controlling the specific gravity of the separating media at 1.40, 1.50, 1.60, and 1.80. The emission standards evaluated consist of 0.6, 1.2, 2.0, and 4.0 lb $SO_2$/MBtu emission limits and the 1979 new source performance standards (NSPS).

TABLE S-1. SELECTED CHARACTERISTICS AND EQUIVALENT

$SO_2$ CONTENTS OF THE PREMISE COALS

| Coal | Pyritic sulfur, % | Total sulfur, % | Ash, % | Moisture, % | Heat content, Btu/lb | Equivalent $SO_2$ content in coal, lb $SO_2$/MBtu |
|---|---|---|---|---|---|---|
| Illinois No. 6 seam | 3.27 | 4.34 | 29.39 | 1.36 | 9,667 | 8.97 |
| Pittsburgh seam | 2.15 | 3.67 | 13.81 | 3.42 | 12,121 | 6.05 |
| Upper Freeport seam | 1.88 | 2.32 | 16.80 | 5.60 | 11,668 | 3.97 |
| Cedar Grove seam | N.A. | 0.85 | 16.04 | 6.60 | 11,680 | 1.45 |

Basis: All values are on an as-received basis.

The economic premises are based on regulated utility operations. Capital investments, first-year annual revenue requirements, and levelized annual revenue requirements are determined. The costs are projected to 1982 for the capital investment and to 1984 for the annual revenue requirements.

## RESULTS AND ILLUSTRATIVE EXAMPLES OF MODEL USE

The results obtained from this model can be used in many ways, some of which are listed below.

- To determine the most economical method of $SO_2$ control by using coal cleaning, FGD, or their combination.
- To illustrate the effects of changes in process conditions on the performance and economics of a coal-cleaning, an FGD, or a combined coal-cleaning - FGD process.
- To analyze the effect of coal cleaning on power plant operations by considering various benefits and penalties attributable to coal cleaning.
- To compare the process performance and economics for different coal-cleaning and FGD process designs.

These do not exhaust all possible uses, but they should provide an indication of the potential uses of the model.

The main objectives of this report are to make potential users of this model aware of its availability and to illustrate some of its possible uses. To accomplish the latter, the model was used to simulate a wide range of operating conditions. Eighty runs were made using the four premise coals, cleaned at four specific gravities of separation, and with the flue gas restricted to five $SO_2$ emission limits. Other trial runs of the combined model were made by varying such operating conditions as cleaned coal topsize, power plant megawatt rating, and the distance from the cleaning plant to the power plant.

### Coal-Cleaning Operating Performance

For the application of coal cleaning to $SO_2$ emission control, the important performance criteria relating to costs are yield, sulfur removal efficiency, and Btu recovery. In a coal-cleaning plant, the mix of equipment and the specific gravity of separation usually control the properties of the cleaned coal, and thus the sulfur reduction and cost of the process. For the single plant configuration used in this study, the primary input variable used to define the cleaning process operating conditions was the specific gravity of separation. Among the important performance criteria determined by the specific gravity of separation are the yield (weight of product divided by weight of raw coal feed), the sulfur reduction efficiency, and the Btu recovery. The yield is a measure of the amount of material mined, processed, and later discarded as refuse. The sulfur reduction efficiency is determined by the coal washability and the amount and size distribution of coal minerals, especially pyrite. The Btu recovery is the percentage of the Btu content of the raw coal that remains in the cleaned coal. It is a measure of both the cleaned coal properties and the economics of the process since the Btu loss in the refuse is an important economic factor in coal cleaning.

The relationships between specific gravity of separation and the resulting yield, sulfur reduction efficiency, mineral removal, and Btu recovery, which depend on the characteristics of the raw coal, are shown in Table S-2. Yield and Btu recovery decreases as the specific gravity of separation decreases. This is to be expected because the quantity of pure coal lost to the cleaning plant refuse increases as the specific gravity decreases. As the specific gravity of separation decreases, the sulfur reduction increases as a result of the increased pyritic sulfur removed. There is thus a tradeoff between high-Btu recovery and high-sulfur removal.

TABLE S-2. SULFUR REDUCTION AND BTU RECOVERY BY COAL CLEANING

|  | Raw coal | Coal-cleaning operating, specific gravity 1.4 | 1.5 | 1.6 | 1.8 |
|---|---|---|---|---|---|
| **Illinois No. 6 Coal** |  |  |  |  |  |
| Yield, % | - | 56 | 65 | 68 | 73 |
| lb $SO_2$/MBtu[a] | 8.97 | 3.86 | 4.18 | 4.38 | 5.08 |
| Sulfur reduction, % | - | 57 | 53 | 51 | 43 |
| Btu recovery, % | - | 78 | 88 | 92 | 96 |
| **Pittsburgh Coal** |  |  |  |  |  |
| Yield, % | - | 73 | 83 | 86 | 91 |
| lb $SO_2$/MBtu[a] | 6.05 | 3.79 | 4.18 | 4.37 | 4.68 |
| Sulfur reduction, % | - | 37 | 31 | 28 | 23 |
| Btu recovery, % | - | 82 | 92 | 95 | 97 |
| **Upper Freeport Coal** |  |  |  |  |  |
| Yield, % | - | 67 | 78 | 82 | 88 |
| lb $SO_2$/MBtu[a] | 3.97 | 1.76 | 1.93 | 2.03 | 2.35 |
| Sulfur reduction, % | - | 56 | 51 | 49 | 41 |
| Btu recovery, % | - | 78 | 89 | 93 | 97 |
| **Cedar Grove Coal** |  |  |  |  |  |
| Yield, % | - | 78 | 80 | 81 | 83 |
| lb $SO_2$/MBtu[a] | 1.45 | 1.17 | 1.20 | 1.23 | 1.25 |
| Sulfur reduction, % | - | 19 | 17 | 15 | 14 |
| Btu recovery, % | - | 91 | 93 | 95 | 96 |

a. Assuming 100% conversion of sulfur to $SO_2$.

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**FGD Operating Performance**

The FGD process design used in this illustration removes 90% of the $SO_2$ in the flue gas that is scrubbed. If the overall $SO_2$ removal requirement of the FGD system is less than 90%, a portion of the gas is bypassed to allow the scrubber to operate at the 90% removal level. The bypassed flue gas is then used to reduce the steam requirements for reheating the scrubbed flue gas by recombining both gas streams. For this reason, the amount of bypass is the most important FGD operating condition affecting the FGD design. The portion of flue gas bypassed is determined by the emission limit, the heating value, the sulfur content of the fired coal, and the sulfur content of the ash.

**Economics**

One possible use of the combined computer model is to determine the combination of coal cleaning and FGD that will meet the specified emission limit at the minimum overall cost. The operating conditions for this optimum combination are not the same for every case because they can change with variations in coal properties, process characteristics (e.g., cleaning equipment efficiencies), and with the particular cost element chosen for the analysis. The cost elements that the model calculates include the capital investment, first-year annual revenue requirements, and levelized annual revenue requirements; each of which can be generated for either a coal-cleaning process, a combined coal-cleaning - FGD process, or just an FGD process, depending on the user specifications. In the case of the combined coal-cleaning - FGD process, the net cost is the sum of the cost for the coal-cleaning process, adjusted by any benefits and penalties (including the cost differential for the FGD process).

Capital Investment--

The coal-cleaning capital investments generated by the model for the cases with the Pittsburgh coal at the four cleaning levels with a 1.2 lb $SO_2$/MBtu emission limit are shown in Figure S-4. The actual coal-cleaning capital investment is shown, along with the changes in FGD and the sum of the economic benefits and penalties. The net capital investment is the capital investment of the coal-cleaning plant plus the changes in the capital investment of the FGD process and the other economic benefits and penalties (in this case both are negative). For Btu recovery levels below about 95%, the combined coal-cleaning - FGD process results in a net saving in capital investment, compared with FGD alone, while above a Btu recovery of about 95%, FGD alone is more economical. There is also an inflection in the net capital investment curve at about 75% Btu recovery, representing the cleaning level that provides the minimum capital investment for these particular conditions.

Annual Revenue Requirements--

A similar comparison of levelized annual revenue requirements is shown in Figure S-5. The effect of coal cleaning on FGD annual revenue requirements is similar to its effect on capital investment. The net effect of the other economic benefits and penalties is to reduce costs rapidly with increasing Btu recovery, reaching a minimum at about 95% Btu recovery, then these costs rapidly increase at higher recovery levels. The rapid change in the sum of

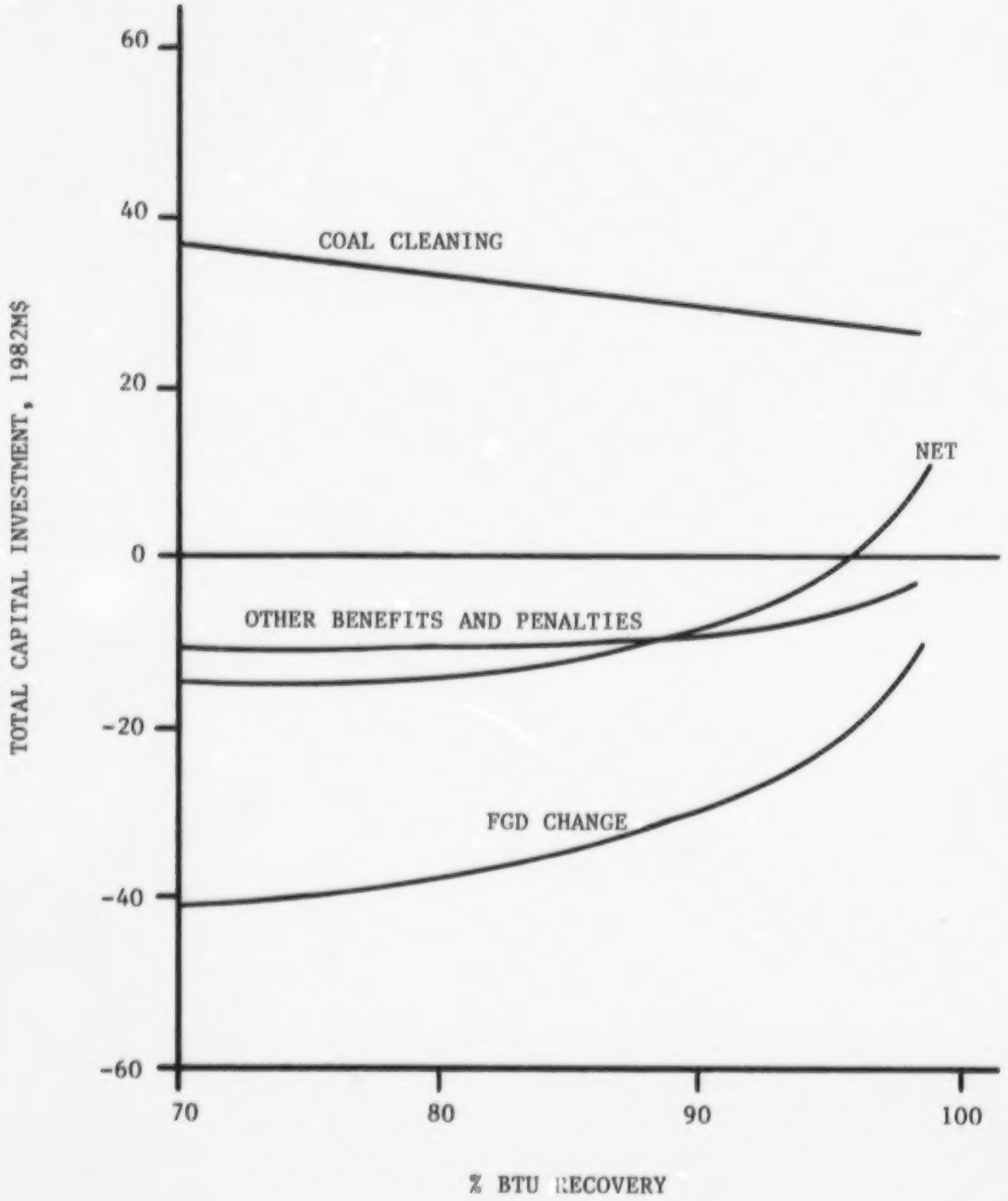

Figure S-4. Effect of Btu recovery on the net total capital investment, Pittsburgh coal at 1.20 emission limit.

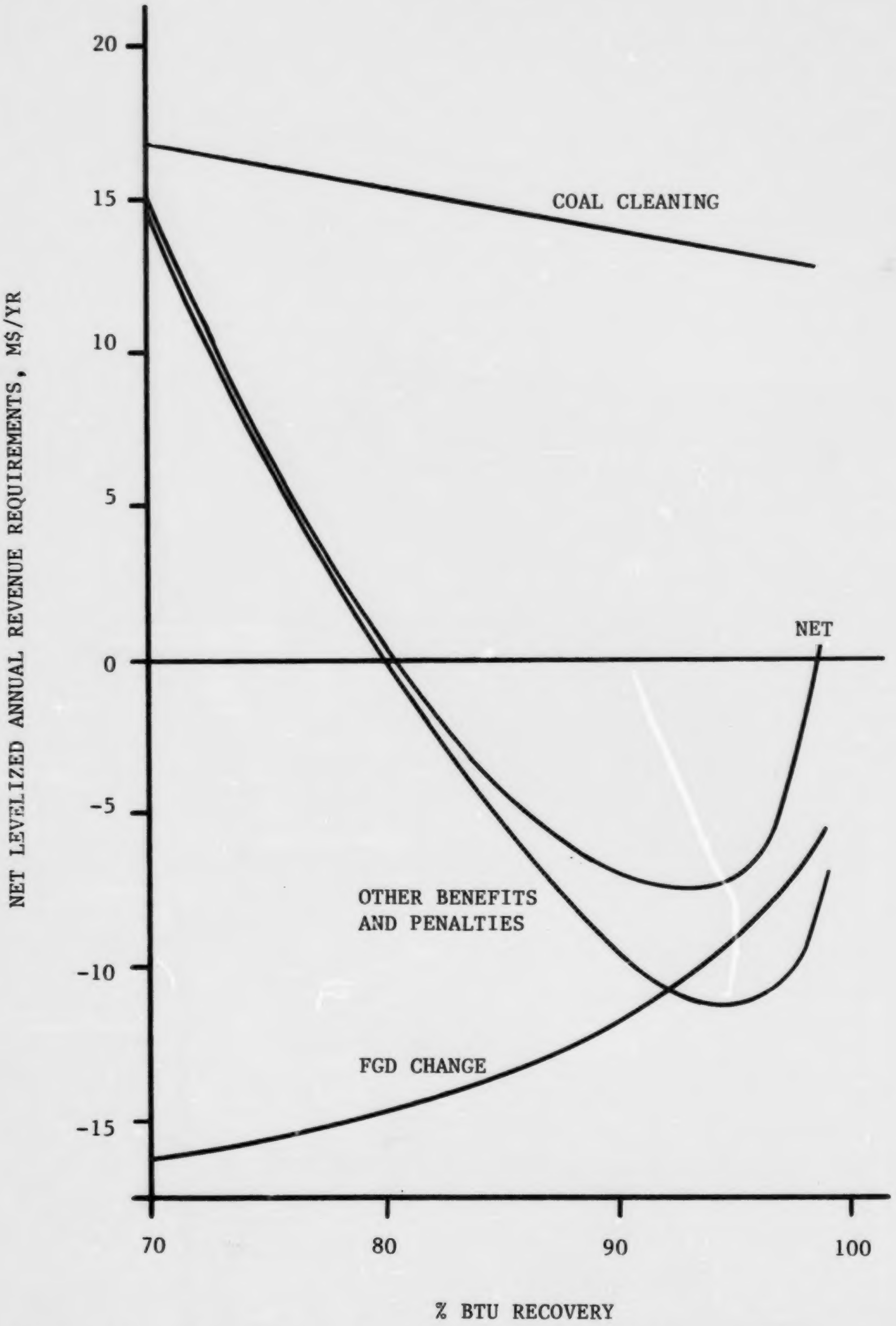

Figure S-5. Effect of Btu recovery on the net levelized annual revenue requirements, Pittsburgh coal at 1.20 emission limit.

the other economic benefits and penalties is due primarily to the influence of Btu loss on the total costs. As a result, the combined coal-cleaning - FGD process has lower annual revenue requirements than an FGD process alone in a range of Btu recoveries from about 98% to about 80%, with a minimum at about 93%.

As seen in Figures S-4 and S-5, there is a range of coal-cleaning efficiencies in which the combined coal-cleaning - FGD process has both a lower capital investment and lower annual revenue requirements than those of FGD alone. The combined process also has a minimum capital investment and a minimum annual revenue requirement at a particular cleaning efficiency which do not coincide. The change in the case of capital investment is a result of tradeoff between coal-cleaning and FGD costs. Btu recovery is reduced and FGD costs are reduced more than coal-cleaning costs are increased. The relative change in annual revenue requirements is a combination of the capital and operating cost tradeoffs. FGD operating costs decrease, and other coal quality related benefits increase with decreasing Btu recovery. This continues until the cost of coal lost to the refuse more than offsets the total benefits. The same general pattern occurs with the other coals and at most of the emission levels evaluated although the minima occur at different points for different coals and emission levels. In optimizing a combined coal-cleaning - FGD process, the annual revenue requirements are usually considered to be more important than the total capital investment; therefore, the operating conditions producing the minimum revenue requirements are usually selected for process optimization.

Figure S-6 illustrates the reduction in levelized annual revenue requirements for the four coals at different $SO_2$ emission limits as compared to sulfur removal with FGD alone. Significant differences in levelized annual revenue requirements result from differences in coal washability. Also, the economics generally become more favorable as the $SO_2$ emission limits become less stringent; however, the curves for the Cedar Grove and Upper Freeport coals do have a maximum point beyond which the economics become less favorable. These maxima are located at the points where the optimum pollution control process changes from a combined coal-cleaning - FGD process to a coal-cleaning process, alone. In the cases of the curves for the Illinois No. 6 and Pittsburgh coals, these curves did not reach the point at which coal cleaning could provide the most economical pollution control process without some degree of FGD being necessary.

## PROJECT CONCLUSIONS AND RECOMMENDATIONS

A computer model capable of calculating the economics of coal-cleaning processes alone and combined with FGD in utility applications has been successfully developed. When selected values from the model were compared with values obtained from manual calculations, the maximum difference was less than 1.5%.

The illustrative runs had coal-cleaning sulfur removals from 14% to 57% using four premise coals, and showed that coal cleaning alone met some less

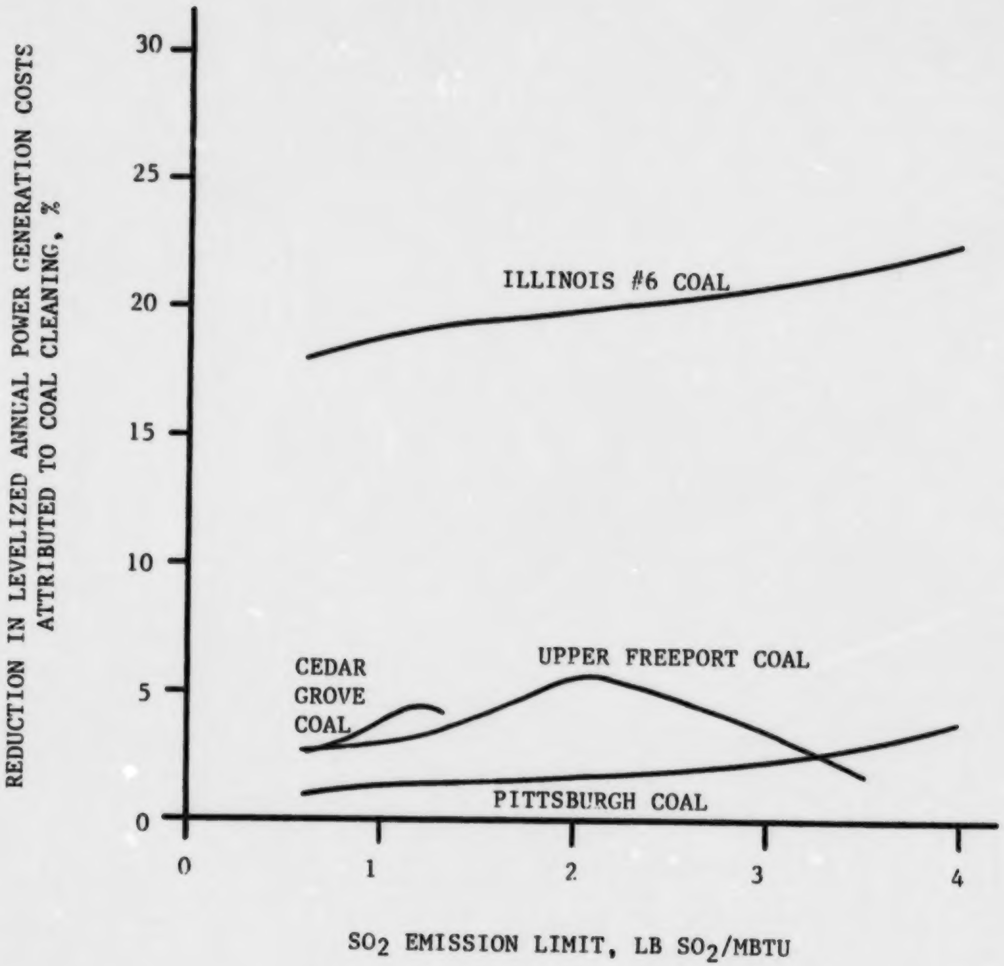

Figure S-6. Effect of emission limit on the power generation cost reduction attributable to coal cleaning (at optimum specific gravity).

stringent emission limits. Some of the combined coal-cleaning - FGD process had a specific gravity of separation at which costs were at a minimum. Coal cleaning reduced the FGD costs in all cases, primarily by allowing more flue gas to be bypassed. In some cases, this reduction in FGD costs did not offset the costs of coal cleaning. For this reason, case-by-case comparisons must be made to determine the most economical approach.

Economic benefits and penalties estimates incorporated into the model indicated that the use of coal cleaning and FGD would provide total capital investment changes ranging from a $136 million benefit to a $7.6 million penalty when compared with an FGD process, alone. Similarly, net annual revenue changes associated with coal cleaning ranged from a $134 million benefit to a $2.9 million penalty per year for the cases studied.

For the cases studied, it was found that the use of coal cleaning in combination with FGD can have a varied effect on the levelized annual cost of power production. This effect, which is dependent on the coal and the specific operating conditions, ranges from a 0.5% increase to a 22.6% decrease in those costs.

The methods used to determine many of the other economic benefits and penalties of coal cleaning are necessarily general in nature because detailed data relating specific coal properties to boiler performance and operating costs are scarce. Thus, development and incorporation of more detailed and quantitative data in the model would greatly increase the usefulness of the model in assessing overall economic effects of coal cleaning. Similarly, the scope of the model could be increased by incorporating other coal-cleaning processes and alternate emission control processes such as fabric filter baghouses and spray dryer FGD and by modifying the functions to allow multiple simultaneous simulations. The economics of retrofit situations should also be considered.

Studies should be made to more accurately define the effects of coal cleaning on power production. In particular, improvements are needed in the relationship used by the economic benefits and penalties program to determine the effect of coal cleaning on power plant availability and capacity.

An option to use a baghouse instead of an ESP should be included in the benefits and penalties program. Such an option would be particularly valuable in cases involving low-sulfur coals.

The coal-cleaning program developed for this project should be combined with other computer models (e.g., a spray dryer model) to simulate a wider variety of process combinations.

The coal-cleaning program should be used to simulate the performance of other coal-cleaning process designs by developing the necessary capital and operating cost data along with the operating performance relationships.

The combined model should be revised as conditions warrant to ensure that the performance and economic data remain up-to-date.

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The coal-cleaning program should be adapted to allow more than one case to be executed in a single simulation. This would simplify determination of the optimum operating conditions for the combined process, which is presently a trial and error procedure.

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# INTRODUCTION

For the past 15 years, the Tennessee Valley Authority (TVA) has conducted numerous economic evaluations of utility flue gas desulfurization (FGD) and other emission control processes for the U.S. Environmental Protection Agency (EPA) and other organizations. Detailed design and economic premises for these studies have been established and in some instances the evaluations have been computerized. In 1979, an EPA-sponsored economic evaluation of coal-cleaning processes used in conjunction with FGD was completed (1). This evaluation demonstrated the potential of physical coal cleaning for $SO_2$ emission control and showed the possibility of economically favorable combinations of coal cleaning and FGD in some emission control situations. Furthermore, it has become apparent that the economics of coal cleaning should be assessed in terms of overall costs to the utility since coal cleaning affects many aspects of coal transportation and power plant operation.

As a continuation of the coal-cleaning study, a system of computer programs was developed to model the performance and economics of full-scale coal cleaning in combination with limestone FGD. This computer model uses appropriate algorithms to determine the process design for both processes from which the cost of coal cleaning and the cost differential for FGD are then calculated. This FGD cost differential is simply the difference between the cost of an FGD process that must clean the combustion gas when raw coal is burned and the cost of an FGD process that does the same for cleaned coal. This being the case, this cost differential is considered to be a benefit of coal cleaning, and it is included with the other economic benefits and penalties that accrue as a result of the use of cleaned coal.

This report provides a general description of the combined coal-cleaning - FGD model and illustrates its uses and capabilities. The example runs use only one coal-cleaning and one FGD process design. The model is capable, however, of being modified to simulate other coal-cleaning processes that use gravity separation and froth flotation provided the appropriate equipment performance and economic data are available. Also, numerous FGD process options are available. A users manual describing these options and the use of the model is being prepared.

The model consists of four programs, one which simulates the coal-cleaning process, two which simulate the FGD process, and one which determines the economic benefits and penalties attributable to the use of cleaned coal. Since the model contains about 26,500 lines if all four programs are combined, it would be expensive, if not physically impossible, to execute them as a single program. To alleviate this problem, the model includes a procedure

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that allows the simulation to be performed using common input and output operations available with all but the smallest computer systems.

The coal-cleaning program was adapted from a model developed by Battelle Columbus Laboratories based on a program developed at the University of Pittsburgh (2,3,4). For this project, the Battelle version was obtained from Versar, Inc., who also provided information necessary to adapt the program to the TVA computer system. The program as received from Versar has been modified to conform to the design criteria set down in the premises of this project. Other modifications were necessary to enable this program to be used in conjunction with the other programs comprising the model.

The FGD segment of the model consists of the Shawnee lime/limestone FGD model (5), which was developed by Bechtel National, Inc., and TVA using data from the EPA-sponsored FGD test facility at the TVA Shawnee Steam Plant near Paducah, Kentucky. It provides full-scale design and economic data for several variants of lime and limestone FGD systems and waste disposal systems.

The last segment of the model determines values for various economic benefits and penalties to the overall economics of power plant operation that accrue as a result of coal cleaning. These include such factors as reduced transportation costs (in the case of mine-based cleaning plants), various effects on boiler operation that result from use of the cleaned coal, and reduced ash disposal costs. These act to decrease or increase the cost to the utility of burning cleaned coal as compared with burning the same coal without cleaning. Usually the overall effect of these factors is an economic benefit.

Inputs for the model consist of power plant data, emission limits, coal-cleaning process specifications, FGD design specifications, raw coal properties and washability, and the coal-cleaning plant operating conditions. Based on the heat requirements of the power unit, raw coal properties, and the operating specific gravity in the cleaning plant, the model calculates the quantities and properties of the cleaned coal and the costs of the coal-cleaning process. The FGD requirements and cost differentials are based on the physical and chemical properties of the raw and cleaned coals, power plant design criteria, and the specified emission limit. The other benefits and penalties are based on specific equipment design criteria such as crusher inlet size and certain physical characteristics of the power plant.

The model should be useful in determining comparative economic data for coal-cleaning processes and for combinations of coal-cleaning and limestone or lime FGD processes. The economic information is generated for each process individually, as well as for the entire system, thus allowing the user to analyze the different design and economic elements of the individual processes as well as the combined process. This information would be useful when selecting a combined process for a specific application since the model will show the effects of changing the process variables on the cost of the combined system.

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In addition to cost comparisons, the model allows process performance comparisons to be made by producing material balances, equipment performance and specification data, and coal-cleaning product analyses. The information generated by the model can be used to directly determine relationships between various process variables, and with some trial and error, correlations can be made among some of the more indirectly related process variables (e.g., Btu recovery, coal loss, and reheat energy). This information could also be used to determine the effects of individual process variables on the overall system performance.

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# MODEL DESCRIPTION

The combined coal-cleaning - FGD computer model is not a single computer program but a group of four individual programs linked by a set of computer input/output operations. Three of these programs, one that simulates the coal-cleaning process and two that simulate the FGD process, were developed in earlier EPA-sponsored projects. The fourth program calculates the economic benefits and penalties attributable to the use of cleaned coal, and was developed for this project.

The programs are linked by a series of input and output operations, as seen in Figure 1. The coal-cleaning program receives all input data necessary to execute the combined model and, after the simulation of the coal-cleaning plant is completed, the required data are transferred to the FGD and benefits and penalties programs. At this point, the FGD segment of the model is executed, and additional data required to run the benefits and penalties program are transferred to the corresponding data set. Finally, the benefits and penalties program is executed using the data supplied by the execution of the previous programs, and the combined results are printed as output from the model.

The linkage of the combined model is not as straightforward as might be desired because of the complex set of control statements required to perform a single simulation. These statements will also vary according to the computer used. Without this method of linkage, the execution of the model would be restricted to the largest mainframe computer systems because of the enormous amount of memory that would be required. Also, the process of correcting program errors in a single program of such size would be difficult and expensive.

## MODEL INPUT PROCEDURE

Although each component program in the model can be executed independently, the coal-cleaning program is the nucleus of the model. It is used to control the execution of the other programs by varying the input data that are transferred to them. This is illustrated in Figure 1, which shows that all input data required by the component programs are included in the input data for the coal-cleaning program. The coal-cleaning program then arranges the data into the appropriate input data sets in the order necessary to execute the other programs. This method of transferring the data is used for three reasons. First, it simplifies the many input/output operations of the model, thus reducing the chance of programmer error. Second, the coal-cleaning

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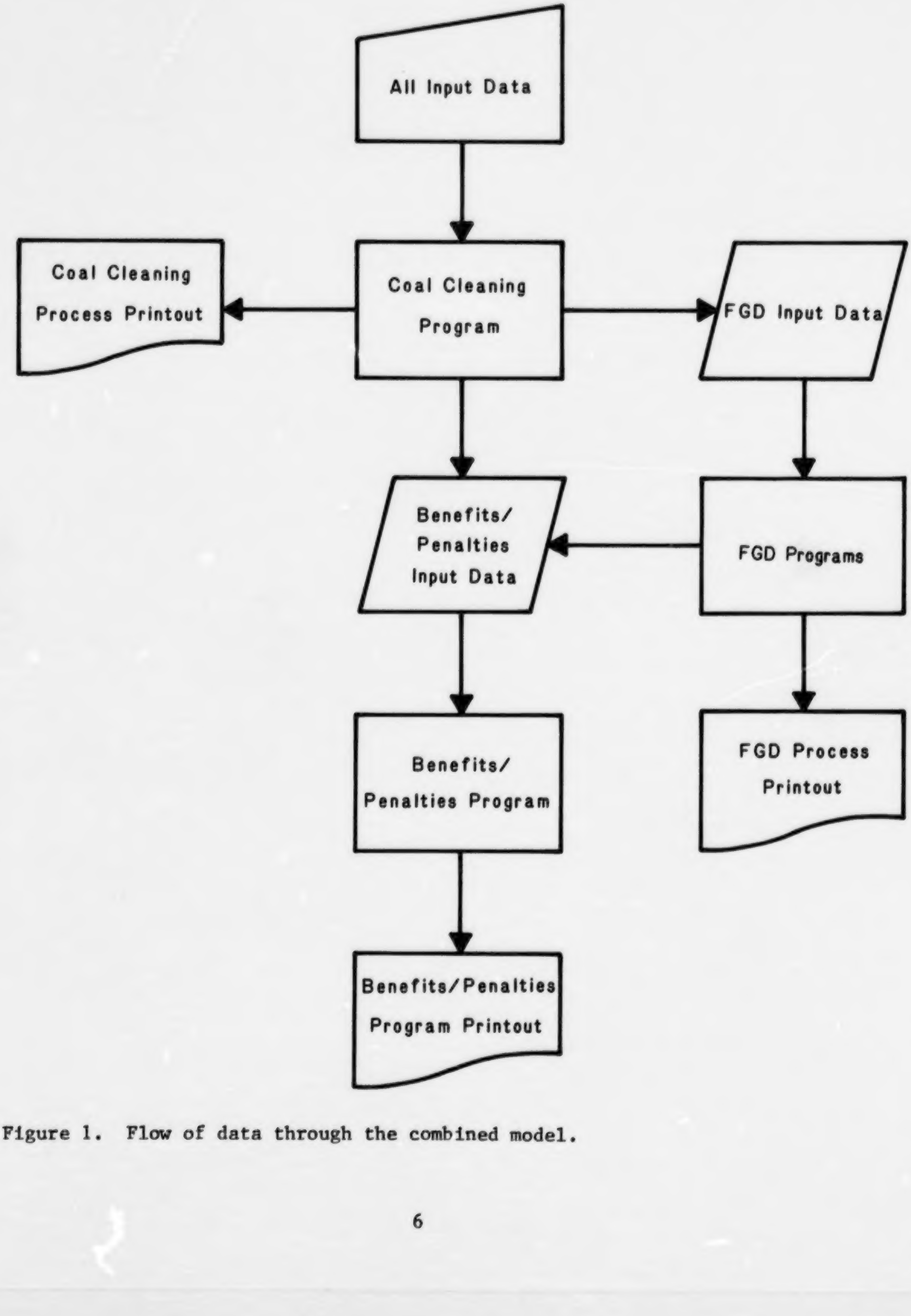
All Input Data
Coal Cleaning Process Printout
Coal Cleaning Program
FGD Input Data
Benefits/ Penalties Input Data
FGD Programs
Benefits/ Penalties Program
FGD Process Printout
Benefits/Penalties Program Printout

Figure 1. Flow of data through the combined model.

program produces information needed to execute the other programs. Third, more than 75% of the original inputs are required to execute the coal-cleaning program.

## COAL-CLEANING PROGRAM

The coal-cleaning program included in this combined coal-cleaning - FGD model was originally developed by Dr. Byron S. Gottfried with the University of Pittsburgh, P. Stanley Jacobsen with the U.S. Bureau of Mines (BOM), and Dr. A. Valliant of Automated Process Surveys, under the joint sponsorship of BOM and EPA (3,4). The original program was modified by Battelle and adapted to simulate the operation of the coal-cleaning facility built at Homer City, Pennsylvania (2). A copy of this program, as modified by Battelle (Coal Preparation Simulation Model Version 4, CPSM4), was supplied to TVA by Versar, Inc., and served as the basis of the coal-cleaning program described in this report. In addition, Versar provided valuable advice on the adaptation of the Battelle program to the TVA computer system.

This coal-cleaning program has been developed around a main driver routine that directs the entire simulation. The 44 subroutines under the control of the main driver are grouped into four areas according to the tasks performed in each.

- Input/Output Operations: This area consists of 22 subroutines that get data into and out of the program. This is a major task, as can be seen by the examples of input and output data in Tables A-5 through A-7 in the appendix.
- Simulation Operations: This area consists of 19 subroutines that perform the calculations required to simulate the unit operations of the coal-cleaning process equipment.
- Economic Calculations: This area consists of a single subroutine (the largest in the coal-cleaning program) that performs certain input and output operations as well as the actual calculations required to produce the coal-cleaning process economics.
- Linkup Operations: This area includes two subroutines that convert data used by the FGD and economic benefits and penalties programs to the required forms and place the data into appropriate data sets.

Although much of the coal-cleaning program is the same as the copy received from Versar, many modifications were made to incorporate it into the combined model. Most of these changes were necessary to produce results that were based on TVA design and economic premises, but others were made to enable the program to operate in conjunction with the other programs in the combined model. The major changes are listed below:

EPA Form 2350-4 (4-80)

- A subroutine was added to the program to allow the ultimate analyses of the cleaned coal and refuse to be calculated from the ultimate analysis of the raw coal and various performance data associated with the plant, such as weight recovery and the ash and sulfur contents of the cleaned and refuse streams.

- The subroutine that accepts the input of equipment performance data was modified to allow equations representing washing equipment distribution curves to be used in addition to the other forms of distribution data.

- A subroutine was added to transfer all necessary data from the coal-cleaning program to the input data sets of the FGD and benefits and penalties programs.

- The subroutine that determines the coal-cleaning process economics was rewritten to produce economic results in accordance with TVA premises.

- Changes were made in two subroutines to enable the flow rate of raw coal to the cleaning plant to be calculated from the power plant design criteria, the heating value of the cleaned coal, and the weight recovery of the cleaning process.

- A subroutine was added to give the user the option of using either proximate or ultimate analysis as the input data for the raw coal.

- The subroutine that determines the moisture content of each flow stream in the process was modified to allow the entire simulation to be performed on a dry basis. However, the material balance printout also includes additional outputs showing the flow rate of the streams with moisture included.

## Coal-Cleaning Program Inputs

Since the combined coal-cleaning - FGD model is complex by nature and the coal-cleaning program accepts, as input data, all the information necessary to execute the model, it follows that the inputs to this program will also be complicated. The primary reason behind the intricate input procedure stems from the fact that the model simulates the performance of two completely different types of processes, thus requiring values for a wide range of process criteria which usually are only related to one of the processes. The complexity of the inputs can also be attributed to the programming styles used in the development of the original programs. This is especially true with regard to the original coal-cleaning program which requires a large amount of input data because it has the capability of simulating almost any physical coal-cleaning process for which the appropriate input data can be obtained.

The input data that must be supplied to the coal-cleaning program can be divided into five categories. Each of these categories is discussed in the

## TABLE 1. UNIT OPERATIONS SIMULATED BY THE COAL-CLEANING PROGRAM AND THE INPUT DATA REQUIRED

| Unit operation | Data required | Equipment type |
|---|---|---|
| Blending | Percent moisture of output flow (optional) | Stream blender |
| Splitting | Percent moisture of upper flow (optional)<br>Percent moisture of lower flow (optional) | Stream splitter |
| Screening | Mesh size in inches<br>Percent moisture in upper flow (optional)<br>Performance data | Dry screen<br>Wet screen |
| Single-stage washing | Specific gravity of separation<br>Percent moisture of clean flow (optional)<br>Washing performance data for each type of equipment | Concentration table<br>Dense-medium vessel<br>Dense-medium cyclone<br>Hydrocyclone<br>Baum jig<br>Classifying cyclone |
| Two-stage washing | Specific gravity of separation<br>Percent moisture of clean flow (optional)<br>Percent moisture of middling flow (optional)<br>Washing performance data for each type of equipment | Two-stage baum jig |
| Froth flotation | Percent moisture of clean flow (optional)<br>Performance data | Froth flotation cell |
| Rotary breaking | Drum length in feet<br>Drum diameter in feet<br>Size of opening in inches<br>Performance data | Rotary breaker |
| Crushing | Crusher setting in inches<br>Performance data | Multiroll crusher<br>Gyratory crusher<br>Single-roll crusher<br>Cage-mill crusher |
| Dewatering | Percent moisture in upper flow | Centrifuge<br>Dryer<br>Filter |

Source: Reference 2.

following paragraphs, and an example of all the input data required to execute the model can be seen in Table A-5 in the appendix.

Miscellaneous Identification and FGD Processing Data--

The initial segment of the input data is composed of the first 17 lines of information in Table A-5. This section contains a wide variety of data, as the title above implies. The first four lines control such things as the type of simulation to be performed (coal cleaning, FGD, or a combination of both), the types of input data the program is to expect (proximate or ultimate coal analysis), and the various types of printouts that are to be produced. The fifth and sixth lines provide the title and description of the particular case being run. The numbers contained in the remaining 11 lines of data in this section provide the values for (1) the coal analysis, (2) the FGD process design parameters, (3) the economic premises for all processes, and (4) the variables which control the many FGD options.

Coal-Cleaning Equipment Inventory--

This segment of input data contains an inventory of the various equipment units that can be used in the coal-cleaning process simulation, along with the related performance data that are used to develop the mathematical relationships employed in the program. The input procedure for this section is necessarily complex because of the wide variety of data, but this section is also the least likely to change once it is placed in the input data file. The amount and type of data required by each equipment unit vary according to the unit operation performed by the particular type of unit. Table 1 gives examples of equipment that perform each of the unit operations supported by the coal-cleaning program, along with the type of data necessary to simulate each.

As can be seen by looking at Table 1, in order to simulate most of the unit operations in the cleaning process, some form of equipment performance data must usually be included with the inputs to the program. These performance data are generally numerical representations (X,Y coordinates) for either a single efficiency curve or a set of efficiency curves. These curves are normally based on the coal size, but as seen in the case of the washing equipment performance data, they can also be based on the equipment's operating specific gravity and the specific gravity of the float-sink fraction being processed. An example of the distribution curve that models the performance of the dense-medium vessel used in the example runs is presented in Figure 2.

In an examination of Figure 2, one sees that this curve relates the percentage of coal in the specified size range that floats in the dense-medium vessel to a given reduced specific gravity. (Reduced specific gravity is the average specific gravity of a particular fraction of the coal fed to the dense-medium vessel divided by the operating specific gravity of the vessel.) Also included on this figure are three equations, along with their respective limits for reduced specific gravity, that can be used to represent this curve. The program is capable of accepting as input either the (X,Y) coordinates representing this curve, or the coefficients, exponents, and reduced specific gravity limits of the equation forms shown in Figure 2. It should be

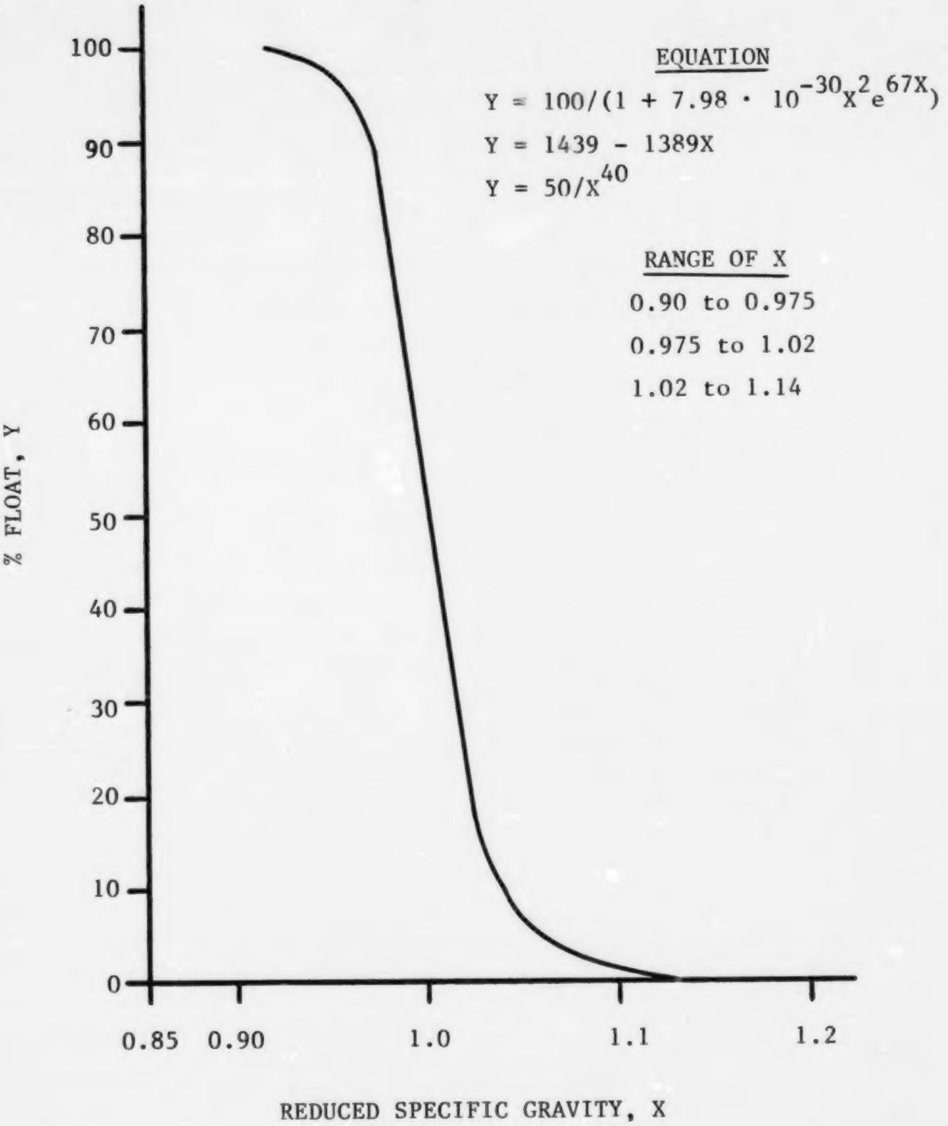

Figure 2. Distribution curve for the dense-medium vessel (3 in. x 3/8 in. coal).

mentioned that more than one curve can be used to represent the equipment. For example, the dense-medium vessel might also have been modeled using one curve for the 3-inch x 2-inch coal, and a different curve for the 2-inch x 3/8-inch coal. The number of curves is determined by the amount of available performance data.

### Coal-Cleaning Process Configuration Data--

Since the coal-cleaning program has the ability to simulate many different process configurations, provided the necessary performance and economic data are available, it is necessary that the particular process configuration be specified in the input data. It is also appropriate that this set of input data follows the coal-cleaning equipment inventory segment since all equipment in the configuration must be present in the inventory so the computer can develop the required mathematical relationships from the respective performance data. In order to prepare this set of inputs, one must have a good understanding of the coal-cleaning process that is to be simulated because these inputs must be in sequence according to the processing order of the configuration. To be more specific, the first equipment unit to process the raw coal must be the first unit in the configuration input data, and the first flow stream in the configuration should be the raw coal fed to the plant. From this point, the input data should follow the logical processing sequence of the plant. This point might be better understood by comparing the input data for the example run (Table A-5) with the coal-cleaning process description that is discussed later in this report.

### Washability Data--

Except for the process design criteria, the washability data are the only inputs that affect the actual performance of the coal-cleaning process being simulated. For this reason, it is of the utmost importance that the input data for the coal washability be as detailed and accurate as possible. This will help to ensure program results that are representative of the process being simulated. The values for coal washability are actually tabulations of selected physical and chemical characteristics for a particular size fraction of the coal that sinks at one specific gravity and floats at a second higher specific gravity. These characteristics must include the weight fraction of the coal that floats at the particular specific gravity interval, expressed as a percentage of all the coal in the size fraction. Also required are the values for the ash, total sulfur, and the heating value of the floating coal. Pyritic sulfur is often included in the data, but is not essential. The complete washability table for the Pittsburgh coal used in the illustrative runs is shown as an example in Table 2.

There is a restriction on the limits of the size fractions used in the washability tables. It is necessary that the size fraction limits be the same as the sizes of the openings of screens used in the process. An example would be a 3/8-inch opening in a prewet screen, which would require that one size fraction in the washability table has 3/8 inch as its lower limit and that another fraction has 3/8 inch as its upper limit. Violating this guideline would cause the program to generate new size data by interpolation and reduce the accuracy of the results.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

## TABLE 2. WASHABILITY DATA FOR THE PITTSBURGH COAL

| | | | Direct, % | | | | Cumulative, % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Size fraction and weight | Specific gravity | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 4.2 inches by 2.97 inches | FLOAT-1.30 | 6.80 | 4.56 | 0.70 | 2.17 | 14,622 | 6.80 | 4.56 | 0.70 | 2.17 | 14,622 |
| % of flow: 3.4 | 1.30-1.35 | 65.00 | 6.12 | 1.78 | 2.38 | 14,383 | 71.80 | 5.97 | 1.68 | 2.36 | 14,406 |
| | 1.35-1.40 | 8.20 | 11.90 | 3.81 | 5.24 | 13,263 | 80.00 | 6.58 | 1.90 | 2.66 | 14,289 |
| | 1.40-1.50 | 9.80 | 21.95 | 3.91 | 5.34 | 11,602 | 89.80 | 8.26 | 2.12 | 2.95 | 13,995 |
| | 1.50-1.60 | 4.30 | 28.68 | 4.06 | 5.49 | 10,486 | 94.10 | 9.19 | 2.20 | 3.06 | 13,835 |
| | 1.60-1.90 | 1.70 | 40.69 | 4.50 | 5.93 | 8,486 | 95.80 | 9.75 | 2.25 | 3.12 | 13,740 |
| | 1.90-2.20 | 2.50 | 55.78 | 8.70 | 10.13 | 5,794 | 98.30 | 10.92 | 2.41 | 3.29 | 13,538 |
| | 2.20-2.50 | 0.80 | 70.20 | 9.95 | 11.38 | 3,357 | 99.10 | 11.40 | 2.47 | 3.36 | 13,456 |
| | 2.50-2.80 | 0.40 | 66.58 | 12.84 | 14.27 | 3,811 | 99.50 | 11.62 | 2.51 | 3.40 | 13,417 |
| | 2.80-SINK | 0.50 | 60.38 | 37.31 | 38.61 | 3,369 | 100.00 | 11.86 | 2.69 | 3.58 | 13,367 |
| 2.97 inches by 1.495 inches | FLOAT-1.30 | 9.41 | 4.14 | 0.66 | 2.14 | 14,692 | 9.41 | 4.14 | 0.66 | 2.14 | 14,692 |
| % of flow: 12.4 | 1.30-1.35 | 58.06 | 6.01 | 1.59 | 3.08 | 14,339 | 67.47 | 5.75 | 1.46 | 2.95 | 14,388 |
| | 1.35-1.40 | 8.71 | 11.42 | 3.40 | 4.88 | 13,358 | 76.18 | 6.40 | 1.68 | 3.17 | 14,270 |
| | 1.40-1.50 | 9.81 | 20.09 | 3.90 | 5.38 | 11,905 | 85.99 | 7.96 | 1.94 | 3.42 | 14,001 |
| | 1.50-1.60 | 3.90 | 27.75 | 4.11 | 5.59 | 10,633 | 89.89 | 8.82 | 2.03 | 3.52 | 13,854 |
| | 1.60-1.90 | 4.00 | 41.21 | 4.81 | 6.30 | 8,381 | 93.89 | 10.20 | 2.15 | 3.63 | 13,621 |
| | 1.90-2.20 | 1.90 | 62.75 | 8.49 | 9.97 | 4,652 | 95.80 | 11.24 | 2.27 | 3.76 | 13,443 |
| | 2.20-2.50 | 2.60 | 71.86 | 9.54 | 11.02 | 3,100 | 98.40 | 12.85 | 2.47 | 3.95 | 13,169 |
| | 2.50-2.80 | 0.90 | 69.79 | 11.91 | 13.39 | 3,324 | 99.30 | 13.36 | 2.55 | 4.04 | 13,080 |
| | 2.80-SINK | 0.70 | 61.06 | 36.52 | 37.93 | 3,289 | 100.00 | 13.70 | 2.79 | 4.28 | 13,011 |
| 1.495 inches by 0.742 inch | FLOAT-1.30 | 14.30 | 3.93 | 0.65 | 1.98 | 14,739 | 14.30 | 3.93 | 0.65 | 1.98 | 14,739 |
| % of flow: 21.2 | 1.30-1.35 | 53.40 | 6.21 | 1.45 | 2.84 | 14,320 | 67.70 | 5.73 | 1.28 | 2.66 | 14,408 |
| | 1.35-1.40 | 9.80 | 10.87 | 3.10 | 4.34 | 13,483 | 77.50 | 6.38 | 1.51 | 2.87 | 14,291 |
| | 1.40-1.50 | 8.50 | 18.74 | 3.94 | 5.08 | 12,153 | 86.00 | 7.60 | 1.75 | 3.09 | 14,080 |
| | 1.50-1.60 | 4.00 | 27.75 | 3.98 | 4.96 | 10,681 | 90.00 | 8.50 | 1.85 | 3.17 | 13,929 |
| | 1.60-1.90 | 3.90 | 42.14 | 4.43 | 5.17 | 8,308 | 93.90 | 9.89 | 1.96 | 3.26 | 13,696 |
| | 1.90-2.20 | 2.70 | 66.16 | 8.28 | 8.60 | 4,195 | 96.60 | 11.47 | 2.13 | 3.40 | 13,430 |
| | 2.20-2.50 | 1.50 | 75.79 | 9.28 | 9.64 | 2,557 | 98.10 | 12.45 | 2.24 | 3.50 | 13,264 |
| | 2.50-2.80 | 1.10 | 75.69 | 11.31 | 11.76 | 2,466 | 99.20 | 13.15 | 2.34 | 3.59 | 13,144 |
| | 2.80-SINK | 0.80 | 61.44 | 35.63 | 37.55 | 3,229 | 100.00 | 13.54 | 2.61 | 3.86 | 13,065 |
| 0.742 inch by 0.371 inch | FLOAT-1.30 | 22.40 | 4.04 | 0.69 | 2.12 | 14,712 | 22.40 | 4.04 | 0.69 | 2.12 | 14,712 |
| % of flow: 21.4 | 1.30-1.35 | 46.60 | 6.21 | 1.38 | 2.65 | 14,333 | 69.00 | 5.51 | 1.16 | 2.48 | 14,456 |
| | 1.35-1.40 | 9.10 | 10.66 | 2.92 | 4.21 | 13,521 | 78.10 | 6.11 | 1.36 | 2.68 | 14,347 |
| | 1.40-1.50 | 8.20 | 17.71 | 4.02 | 5.53 | 12,289 | 86.30 | 7.21 | 1.61 | 2.95 | 14,152 |
| | 1.50-1.60 | 3.70 | 27.13 | 4.48 | 5.76 | 10,734 | 90.00 | 8.03 | 1.73 | 3.07 | 14,011 |
| | 1.60-1.90 | 3.90 | 41.83 | 5.95 | 6.79 | 8,276 | 93.90 | 9.43 | 1.91 | 3.22 | 13,773 |
| | 1.90-2.20 | 2.50 | 68.13 | 6.12 | 6.45 | 3,977 | 96.40 | 10.95 | 2.02 | 3.30 | 13,519 |
| | 2.20-2.50 | 1.70 | 79.21 | 7.47 | 7.91 | 2,077 | 98.10 | 12.14 | 2.11 | 3.38 | 13,321 |
| | 2.50-2.80 | 1.40 | 80.14 | 7.59 | 8.11 | 1,911 | 99.50 | 13.09 | 2.19 | 3.45 | 13,160 |
| | 2.80-SINK | 0.50 | 61.50 | 33.08 | 35.63 | 3,554 | 100.00 | 13.34 | 2.34 | 3.61 | 13,112 |

(Continued)

TABLE 2. (Continued)

| Size fraction and weight | Specific gravity | Direct, %<br>Weight | Direct, %<br>Ash | Direct, %<br>Pyritic sulfur | Direct, %<br>Total sulfur | Direct, %<br>Btu/lb | Cumulative, %<br>Weight | Cumulative, %<br>Ash | Cumulative, %<br>Pyritic sulfur | Cumulative, %<br>Total sulfur | Cumulative, %<br>Btu/lb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.371 inch by 28 mesh | FLOAT-1.30 | 24.10 | 3.11 | 0.55 | 1.84 | 14,883 | 24.10 | 3.11 | 0.55 | 1.84 | 14,883 |
| % of flow: 37.1 | 1.30-1.35 | 38.90 | 5.90 | 1.29 | 2.55 | 14,390 | 63.00 | 4.83 | 1.01 | 2.20 | 14,579 |
|  | 1.35-1.40 | 10.50 | 9.84 | 2.79 | 4.09 | 13,664 | 73.50 | 5.55 | 1.26 | 2.54 | 14,448 |
|  | 1.40-1.50 | 7.10 | 15.95 | 4.17 | 5.19 | 12,613 | 80.60 | 6.46 | 1.52 | 2.77 | 14,286 |
|  | 1.50-1.60 | 3.10 | 25.06 | 5.28 | 6.92 | 11,006 | 83.70 | 7.15 | 1.66 | 2.92 | 14,165 |
|  | 1.60-1.90 | 6.30 | 48.46 | 6.05 | 6.81 | 7,185 | 90.00 | 10.04 | 1.96 | 3.20 | 13,676 |
|  | 1.90-2.20 | 2.80 | 65.33 | 5.31 | 5.87 | 4,459 | 92.80 | 11.71 | 2.07 | 3.28 | 13,398 |
|  | 2.20-2.50 | 4.00 | 82.83 | 5.26 | 5.51 | 1,605 | 96.80 | 14.65 | 2.20 | 3.37 | 12,911 |
|  | 2.50-2.80 | 2.50 | 86.77 | 4.63 | 4.77 | 997 | 99.30 | 16.47 | 2.26 | 3.40 | 12,611 |
|  | 2.80-SINK | 0.70 | 64.20 | 31.09 | 33.05 | 3,258 | 100.00 | 16.80 | 2.46 | 3.61 | 12,545 |
| 28 mesh by 0 inch | FLOAT-1.30 | 33.20 | 3.00 | 0.62 | 1.91 | 14,898 | 33.20 | 3.00 | 0.62 | 1.91 | 14,898 |
| % of flow: 4.5 | 1.30-1.35 | 20.70 | 6.42 | 1.17 | 2.77 | 14,281 | 53.90 | 4.31 | 0.83 | 2.24 | 14,661 |
|  | 1.35-1.40 | 7.90 | 9.22 | 2.24 | 3.60 | 13,788 | 61.80 | 4.94 | 1.01 | 2.41 | 14,549 |
|  | 1.40-1.50 | 6.70 | 14.08 | 3.11 | 4.64 | 12,930 | 68.50 | 5.83 | 1.22 | 2.63 | 14,391 |
|  | 1.50-1.60 | 4.40 | 21.95 | 4.64 | 5.60 | 11,605 | 72.90 | 6.81 | 1.42 | 2.81 | 14,223 |
|  | 1.60-1.90 | 6.70 | 37.38 | 6.18 | 6.91 | 9,007 | 79.60 | 9.38 | 1.82 | 3.16 | 13,784 |
|  | 1.90-2.20 | 3.80 | 59.12 | 6.59 | 7.02 | 5,430 | 83.40 | 11.65 | 2.04 | 3.33 | 13,403 |
|  | 2.20-2.50 | 5.60 | 78.79 | 4.34 | 4.64 | 2,311 | 89.00 | 15.87 | 2.19 | 3.41 | 12,705 |
|  | 2.50-2.80 | 8.40 | 87.60 | 3.49 | 3.96 | 890 | 97.40 | 22.06 | 2.30 | 3.46 | 11,686 |
|  | 2.80-SINK | 2.60 | 69.48 | 28.93 | 29.77 | 2,587 | 100.00 | 23.29 | 2.99 | 4.15 | 11,450 |
| Composite | FLOAT-1.30 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 |
| % of feed: 100.0 | 1.30-1.35 | 46.05 | 6.08 | 1.42 | 2.72 | 14,350 | 65.72 | 5.32 | 1.18 | 2.49 | 14,486 |
|  | 1.35-1.40 | 9.64 | 10.44 | 2.96 | 4.27 | 13,555 | 75.35 | 5.97 | 1.40 | 2.72 | 14,367 |
|  | 1.40-1.50 | 8.04 | 17.76 | 3.99 | 5.25 | 12,303 | 83.39 | 7.11 | 1.65 | 2.96 | 14,168 |
|  | 1.50-1.60 | 3.62 | 26.48 | 4.56 | 5.90 | 10,833 | 87.01 | 7.92 | 1.77 | 3.09 | 14,030 |
|  | 1.60-1.90 | 4.86 | 44.72 | 5.62 | 6.47 | 7,815 | 91.87 | 9.86 | 1.98 | 3.27 | 13,701 |
|  | 1.90-2.20 | 2.64 | 65.14 | 6.59 | 7.16 | 4,428 | 94.50 | 11.40 | 2.11 | 3.37 | 13,442 |
|  | 2.20-2.50 | 2.77 | 79.78 | 6.47 | 6.92 | 2,032 | 97.27 | 13.35 | 2.23 | 3.48 | 13,117 |
|  | 2.50-2.80 | 1.97 | 83.51 | 6.12 | 6.50 | 1,441 | 99.24 | 14.74 | 2.31 | 3.54 | 12,886 |
|  | 2.80-SINK | 0.76 | 63.58 | 32.81 | 34.59 | 3,195 | 100.00 | 15.11 | 2.54 | 3.77 | 12,812 |

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### Coal-Cleaning Economic Data--

The two remaining sets of input data required by the coal-cleaning program are needed to calculate the coal-cleaning process economics. The first set is used to determine the process capital investment portion of the total capital investment. In order to maintain the flexibility of the program in simulating almost any coal-cleaning process, every process area must be specified by including (1) the type of equation to be used to determine the process capital investment for that area, (2) appropriate values for the coefficients and exponents for the equation, and (3) the number of the flow stream that contains the flow rate on which the calculation is to be based. The types of equations that can be used to determine the area process capital investments are shown in Table 3, with explanations of the values required by each. After all of the area process capital investments are calculated and combined to form the total process capital, the remaining elements of the capital investment, such as indirect investment, contingency, and startup and modification, are determined as specified in the economic premises.

The final set of input data required by the coal-cleaning program supplies information needed to determine the operating and maintenance cost portion of the annual revenue requirements. The equations used in these calculations are in the same exponential form as the third equation form in Table 3. These equations require specification of values for (1) coefficients representing the flow rate and annual quantities on which each equation is based, (2) values for each exponent used in each equation, and (3) the numbers of the flow streams containing the flow rates used in each calculation. The values obtained from these equations are annual quantities, which when multiplied by their respective unit costs, yield annual costs for most of the elements in the conversion cost section of the annual revenue requirements. All remaining elements of the annual revenue requirements are determined as specified in the economic premises.

### Reduced Input Data Set--

As can be seen in Table A-5 in the appendix, the list of input data is formidable, but it can be reduced by almost 70% if appropriate data bases are set up in the computer storage area. Such a reduced input data set, as can be seen in Table A-6, will produce the same results from the combined model as the larger data set. This reduced form of the input data set will only be useful if the results produced by the model are used for comparisons between different coals or process design criteria. It would have no particular use if only one run of the model is made, in which case the online storage file created by the run would be useless.

## Coal-Cleaning Program Printout

The printout produced by the coal-cleaning program is divided into three sections: input, execution, and output. An example of the tables in each of the sections is included in the base case printout that is reproduced in part in the appendix. The individual subsections that make up these major sections are listed below.

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## TABLE 3. ACCEPTABLE EQUATION FORMS FOR DETERMINING THE PROCESS AREA INVESTMENT

| Equation form | Symbol definition |
|---|---|
| $I = A$ | I = Area investment<br>A = Constant, independent of flow |
| $I = AX$ | I = Area investment<br>A = Cost coefficient<br>X = Flow rate variable |
| $I = A(X/B)^e$ | I = Area investment<br>A = Base cost coefficient<br>X = Flow rate variable<br>B = Flow rate value corresponding to base cost<br>e = Cost exponent |
| $I = A(X/B)^e + C(Y/D)^f$ | I = Area investment<br>A = First base cost coefficient<br>X = First flow rate variable<br>B = Flow rate value corresponding to first base cost<br>e = First cost exponent<br>C = Second base cost coefficient<br>Y = Second flow rate variable<br>D = Flow rate value corresponding to second base cost<br>f = Second cost exponent |

Note: All constants, coefficients, exponents, base flow rate values, and table functions are user supplied, but all flow rate values are determined from code numbers supplied by the user to identify the flow streams used to calculate the area investment.

Source: Reference 2.

Input Section

- Raw coal characteristics
- Power plant characteristics
- Stack $SO_2$ emission data

- Equipment identification
- Flow stream identification
- Specific gravity analysis of flow stream No. 1

Execution Section

- Summaries of performance characteristics for every equipment unit
- Specific gravity analyses for every flow stream

Output Section

- Summary data for all units
- Summary data for all flow streams
- Ultimate analyses of raw coal, cleaned coal, and refuse
- Capital investment for the coal-cleaning process
- Annual revenue requirements for the coal-cleaning process

In the input section are printed selected input data in order to guarantee that no errors were made during the input operation. The first two subsections print various values for the raw coal and power plant characteristics. The stack $SO_2$ emission data subsection contains two values. These are the potential combustion concentration of $SO_2$ in the raw coal (the emission level assuming all sulfur is emitted as $SO_2$) and the actual stack $SO_2$ emission level that would result from burning the raw coal. The remaining subsections in the input section are similar to the corresponding sections in the version of the program received from Versar. Of these, the fourth and fifth subsections are listings of the equipment units and the different flow streams included in the process configuration being simulated (2). The last subsection consists of the specific gravity analysis of the raw coal, which is essentially a listing of the washability data of the raw coal.

The execution section of the program printout is the most detailed of the three major sections. For this reason, and because of the repetitive nature of the tables produced, it is also the longest section. This section contains a summary of the performance characteristics for every equipment unit in the configuration. An example of this summary for the dense-medium vessel used in the base case is included in Table A-7 of the appendix. A detailed explanation of the various components of this type of table is provided in the original CPSM4 users guide (2). The other tables in this section have the same format as the table of the washability data in the input section. These tables list specific gravity analyses for all of the flow streams that form the process configuration. It should be noted that this entire section may be omitted from the printout, if desired.

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The output section presents the overall results of the coal-cleaning simulation. The first two tables in this section consist of summary data for the equipment units and the individual flow streams. The second of these is essentially the material balance for the process. The third table contains the ultimate analyses for the raw, cleaned, and refuse coals. The two remaining tables present the capital investment and the annual revenue requirements for the coal-cleaning process. All of these results are based on guidelines discussed in the premise section of this report.

## Coal-Cleaning Process

Coal cleaning or beneficiation is used to remove mineral matter from coal. Historically, the major motivation for these activities has been to reduce the ash level in steam coals and the ash and sulfur levels in metallurgical coals. Since the advent of sulfur emission regulations, many development activities have focused on coal desulfurization (6).

A number of different unit operations are employed in coal preparation. They include size reduction, size classification, coal cleaning, dewatering and drying, and pollution control/waste disposal. Modern commercial coal preparation plants crush coal and separate the particles into a number of size ranges: coarse, medium, and fine. Each size fraction is processed in common or separate circuits using equipment suitable to the size range and cleaning objectives (6).

The coal-cleaning process used for the case studies in this report represents current commercial technology for high efficiency physical coal cleaning (1,7). The process incorporates three types of washing equipment: (1) dense-medium vessels, (2) dense-medium cyclones, and (3) froth flotation cells. The flow diagram of the process is shown in Figure 3, and a description of the major unit operations used in this process design follows.

### Raw Coal Sizing--

The raw coal, used as a feedstock to the coal-cleaning plant, is stored in a stockpile with an assumed topsize of 4 inches. This coal is then transferred by conveyor to a crusher where the topsize is reduced to 3 inches. The crusher operation is simulated by assuming the outlet stream will conform to the Rosin-Rammler equation for size distribution (8). The resulting distribution of the coal coming out of the crusher is shown in the table which follows, along with that which would result if the crusher was set for a 1-1/2-inch topsize. As can be seen from these values, the crusher not only reduces the topsize of the coal, but it crushes the coal in the smaller size fractions as well. For example, when the coal is crushed from a 4-inch topsize to a 3-inch topsize, not only is the amount of coal in the 4- x 3-inch fraction reduced but the amounts in the 3- x 1-1/2-inch and the 1-1/2- x 3/8-inch fractions are similarly reduced.

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TYPING GUIDE SHEET

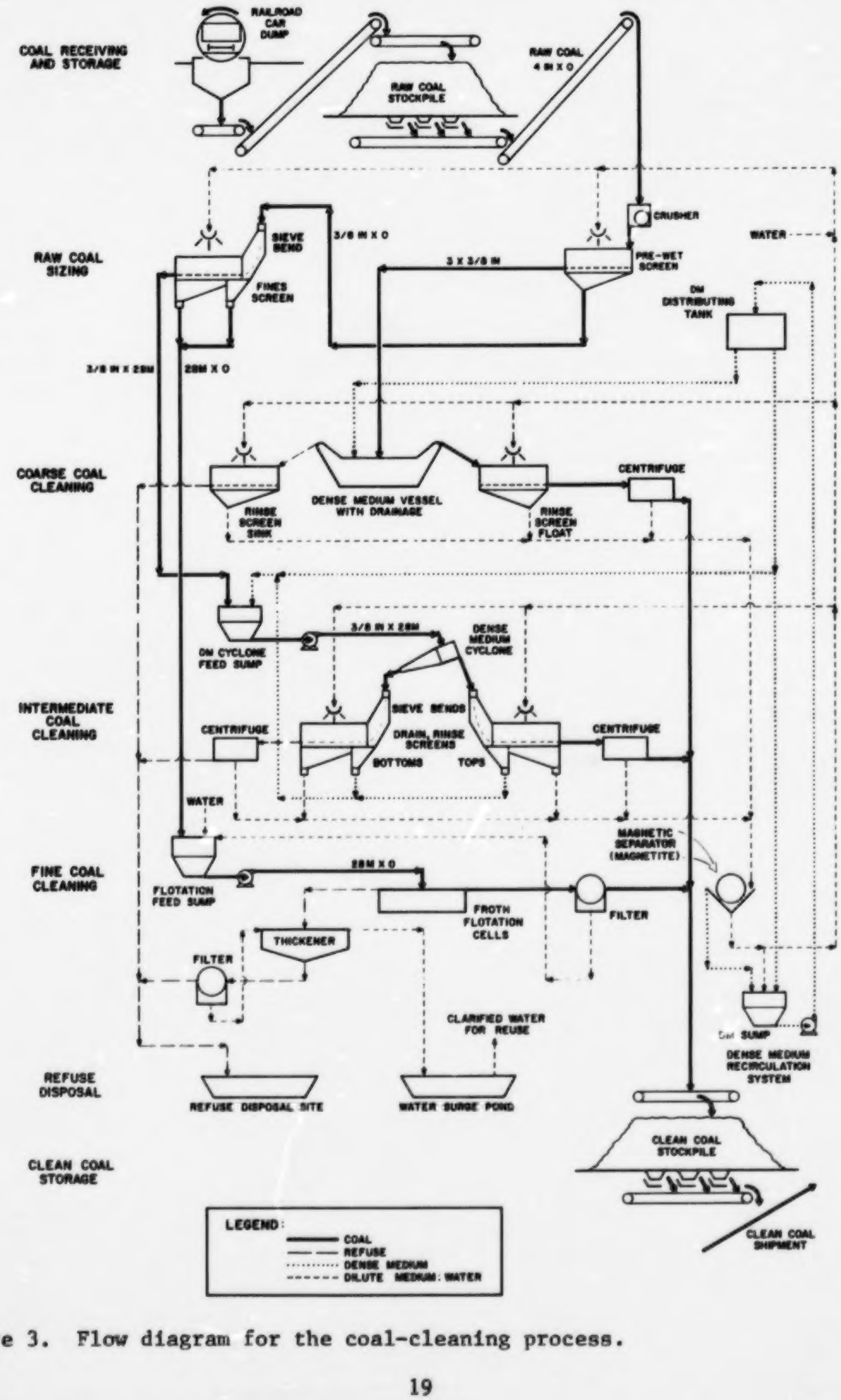
COAL RECEIVING AND STORAGE
RAILROAD CAR DUMP
RAW COAL STOCKPILE
RAW COAL 4 IN X 0
CRUSHER
WATER
RAW COAL SIZING
SIEVE BEND
3/8 IN X 0
FINES SCREEN
3 X 3/8 IN
PRE-WET SCREEN
DM DISTRIBUTING TANK
3/8 IN X 28M
28M X 0
COARSE COAL CLEANING
RINSE SCREEN SINK
DENSE MEDIUM VESSEL WITH DRAINAGE
RINSE SCREEN FLOAT
CENTRIFUGE
DM CYCLONE FEED SUMP
3/8 IN X 28M
DENSE MEDIUM CYCLONE
INTERMEDIATE COAL CLEANING
CENTRIFUGE
SIEVE BENDS
DRAIN, RINSE SCREENS
BOTTOMS
TOPS
CENTRIFUGE
WATER
MAGNETIC SEPARATOR (MAGNETITE)
FINE COAL CLEANING
FLOTATION FEED SUMP
28M X 0
FROTH FLOTATION CELLS
FILTER
THICKENER
FILTER
CLARIFIED WATER FOR REUSE
DM SUMP
DENSE MEDIUM RECIRCULATION SYSTEM
REFUSE DISPOSAL
REFUSE DISPOSAL SITE
WATER SURGE POND
CLEAN COAL STORAGE
CLEAN COAL STOCKPILE
CLEAN COAL SHIPMENT
LEGEND:
COAL
REFUSE
DENSE MEDIUM
DILUTE MEDIUM: WATER

Figure 3. Flow diagram for the coal-cleaning process.

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| Size fraction | Size distribution, weight % 4-inch topsize | 3-inch topsize | 1-1/2-inch topsize |
|---|---|---|---|
| 4 in. x 3 in. | 3.4 | - | - |
| 3 in. x 1-1/2 in. | 12.6 | 2.0 | - |
| 1-1/2 in. x 3/8 in. | 42.4 | 51.9 | 39.8 |
| 3/8 in. x 28 mesh | 37.1 | 39.9 | 48.3 |
| 28 mesh x 0 | 4.5 | 6.3 | 12.0 |

The crushed coal is separated into coarse, intermediate, and fine coal size fractions by the prewet screen and the fines screen. On the prewet screen, the 3-inch x 0 crushed coal is screened at 3/8 inch. The 3- x 3/8-inch coal in the screen overflow is transferred to the coarse coal-cleaning circuit, and the 3/8-inch x 0 fraction in the underflow is transferred to the fines screen. In order to increase the screening efficiency of the prewet screen, the coal is sprayed with water. The resulting separation efficiency is assumed to be 100%, meaning there will be no coal particles less than 3/8 inch in the prewet screen overflow. This is admittedly very unlikely; however, the actual effect of this assumption is negligible in the design calculations.

The 3/8-inch x 0 fraction from the underflow of the prewet screens is separated at 28 mesh on the fine coal screens. Actually each fine coal screen is a combination of a sieve bend and a vibrating screen. The sieve bend is used primarily to remove most of the wash water added by the prewet screens, but some coal classification is also achieved. The water removal is necessary to allow further spraying in the screens which increases the classification efficiency. Again, the resulting screening efficiency is assumed to be 100%. The 3/8-inch x 28-mesh overflow from these screens goes on to the intermediate coal-cleaning circuit and the 28-mesh x 0 fraction underflow goes to the fine coal-cleaning circuit.

Most of the wash water used in the raw coal sizing equipment accumulates in the underflow from the sieve bends and fines screens. Any increase in surface moisture in the two coarser streams over that in the raw coal accounts for the rest of the wash water. This accumulation of water in the 28-mesh x 0 fraction is no problem because this stream is mixed with additional process water in the fine coal-cleaning circuit. From 90 to 120 gallons of wash water is used for each ton of coal on each screen in the raw coal sizing area (1).

Coarse Coal Cleaning--

Trough-type dense-medium vessels are used to clean the 3- x 3/8-inch coal. The raw coal is fed to the dense-medium bath and is moved horizontally through the vessel by a chain and flight conveyor. As the clean coal rises in the bath, it is picked up by the conveyor and moved up an inclined drain screen allowing excess medium to return to the vessel. As the conveyor moves along the bottom of the vessel in the opposite direction, it picks up the refuse and moves it up another drain screen at the opposite end of the vessel.

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The separation medium for the dense-medium vessel is a dilute slurry of fine magnetite particles. The specific gravity of the slurry is 1.60 for the base case process. The coal that floats in this liquid moves through the vessel at about 0.2 $ft^3$/sec/ft of vessel width (1). As the cleaned coal and refuse leave the vessel, they cross rinse screens where they are sprayed with water to reclaim the magnetite. This recovery circuit allows the magnetite makeup requirement for the vessel to remain quite low because only the residual magnetite clinging to the cleaned coal and refuse needs to be replaced.

After leaving the rinse screen, the cleaned coal is dewatered in a vibrating basket centrifuge to 2.25% surface moisture and transferred to the cleaned coal stockpile. The supernatant liquid is added to the magnetite recovery circuit to further reduce the magnetite makeup requirement.

Intermediate-Size Coal Cleaning--

The 3/8-inch x 28-mesh coal is cleaned in a dense-medium cyclone. Again, the separation medium is a magnetite slurry. For the base case, the specific gravity is 1.60. The coal is mixed with the dense medium in a pulping (slurrying) tank to form a slurry before it is processed in the cyclones. After the separation is made, the cleaned coal and refuse are transferred to separate rinse screens where most of the magnetite is reclaimed by spraying with water. This is followed by dewatering of both the cleaned coal and the refuse in vibrating basket centrifuges.

The pulping process is performed in two parallel feed sumps using the moist raw coal from the overflow of the fines screens and the reclaimed magnetite slurry from the drain screens with a small amount of makeup magnetite slurry. The ratio of dense medium to coal is 5:1 in the sumps, but it can decrease to 4:1 without affecting the operation (1).

The dense-medium cyclones have a cone angle of 20 degrees and the axes are inclined at 10 degrees above the horizontal (1). This minimizes the difference in height between the top and bottom of the cyclones and allows the cyclones to be drained during shutdown. In addition to the separation of the cleaned coal and refuse as overflow and underflow, there is also a separation of the dense medium because the effective specific gravity in the cyclone is slightly higher than that of the inlet dense medium. This results in a lower specific gravity for the dense medium in the overflow than in the underflow. However, this difference is eliminated when the dense-medium streams from the cleaned coal and refuse drain screens are recombined and recycled.

The drain screens for the cleaned coal and refuse from the dense-medium cyclones are similar to the fines screens used in the raw coal sizing area; i.e., each one is actually a combination of a sieve bend and vibrating screen. In this case, the sieve bends remove most of the magnetite and water; further magnetite recovery is achieved by spraying the coal with water as it crosses vibrating screens.

As in the coarse coal-cleaning area, the cleaned coal is dewatered in a vibrating basket centrifuge. In this case, the refuse product is also dewatered in a basket centrifuge. Both products have 5.25% surface moistures. The cleaned coal is transferred to the cleaned coal stockpile.

The magnetite in the effluent from the rinse screens is recovered by magnetic separators. These separators contain two magnetized rolls mounted horizontally, one behind the other, which rotate slowly to collect the magnetite from the rinse water. The thick magnetite slurry collected on the drums is then scraped off and recycled to the dense-medium circuits.

### Fine Coal Cleaning--

The 28-mesh x 0 coal fraction from the raw coal sizing area is approximately 6% of the raw coal fed to the cleaning plant. Since this is such a small fraction of the total feed, the quality of cleaned coal is not as important in this area as for the other cleaning areas. However, this fraction is a valuable element in the total Btu recovery of the plant; thus, single-stage froth flotation cells are used to clean the entire fine coal fraction.

The feed for the froth flotation cells is produced by combining the 28-mesh x 0 coal slurry with filtrate from the vacuum filter that dewaters the cleaned coal produced in the flotation cells. The cells are designed for a slurry with about 10% solids. This could be reduced to 5% solids if desired, but a proportionate increase in cell size would be needed to achieve the equivalent level of separation (1).

The cleaned coal in the flotation cell overflow is a 20% solids slurry. It is dewatered to 75% solids in a rotary disk vacuum filter. The refuse is removed from the bottom of the cell as a 3% solids slurry and is dewatered to 75% solids in a thickener-filter system. Because of the possibility of slimes in the refuse filter filtrate, the liquid is recycled to the thickener. The overflow from the thickener is piped to a water surge pond from which clarified water is returned for reuse in the cleaning plant. The cleaned coal is transferred to the cleaned coal stockpile.

## FGD PROGRAM

The FGD portion of the model consists of a model (actually two related programs) previously developed by Bechtel and TVA to calculate physical and chemical characteristics, design data, and economics for lime and limestone FGD processes. It is called the Shawnee lime/limestone model because the mathematical design is based on data from EPA-sponsored tests at the FGD test facility at the TVA Shawnee Steam Plant near Paducah, Kentucky. The model is available for use through TVA and has been described in several publications (9-12). It is also described in a users manual published by EPA and TVA (5).

The FGD model has, since its inception in the mid-1970s, undergone many revisions and updates. These changes have been made to reflect current economic data and new process technology. New developments in FGD technology have led to the expansion of the model to include new process options such as: a mobile-bed turbulent contact absorber (TCA), a venturi, a spray tower, or a combination venturi-spray tower absorber option; a direct ponding, sludge dewatering, sludge fixation, or landfill waste disposal option; and various other options. The current users guide for the FGD model (5) and the other publications cited provide detailed explanations of these options.

## FGD Process

The FGD process used in the illustrative examples in this study is a wet-limestone process using a spray tower and pond disposal of waste. (The other processes and options discussed above can be used as well.) A flow diagram of the process is shown in Figure 4 (13). Only one train of absorption equipment is shown. The number of identical trains used depends on the power plant size and the amount of flue gas scrubbed. For the 1,000-MW case with the Pittsburgh coal, eight operating trains and two spares are used. Spares are provided on the basis of an 85% availability factor. A 90% $SO_2$ removal efficiency is used regardless of the flue gas content and emission level. For conditions requiring less than an overall 90% $SO_2$ removal, some of the flue gas is bypassed. This partial scrubbing design is more economical because the bypassed gas can be recombined with the scrubbed gas to reduce or eliminate reheating requirements. Emergency bypass for 50% of the scrubbed gas is also provided. For descriptive and costing purposes, the process is divided into five process areas: (1) raw material handling and preparation, (2) flue gas handling and $SO_2$ absorption, (3) reheat, (4) slurry recirculation, and (5) waste disposal.

### Raw Materials Handling and Preparation--

The raw materials handling and preparation area consists of equipment to receive limestone by truck or rail, a storage pile, live storage equipment, and equipment for crushing and wet ball milling the limestone to the desired size. The slurry from the wet ball mills is pumped to a slurry feed tank adjacent to the scrubbing area which serves all of the absorber trains.

### Flue Gas Handling and $SO_2$ Absorption--

Flue gas from the power plant induced-draft (ID) fans discharges into a plenum that supplies the absorbers. This plenum also contains outlets for two emergency bypass ducts with a combined capacity of 50% of the scrubbed gas. The emergency bypass ducts also serve as regular bypass ducts if flue gas bypass is allowed by the operating conditions.

Each absorber train consists of a spray tower absorber with a presaturator and mist eliminator, a reheater, and an ID booster fan. The flue gas is cooled from 300°F to 127°F in the presaturator by a spray of absorbent liquid and passes upward through the spray tower. It then passes through a mist eliminator, which reduces the moisture content to 0.1%, and through the reheater upstream from the ID fan.

### Reheat--

The reheater is designed to provide a flue gas temperature of 175°F at the stack inlet. The size depends on the quantity of flue gas bypassed. At

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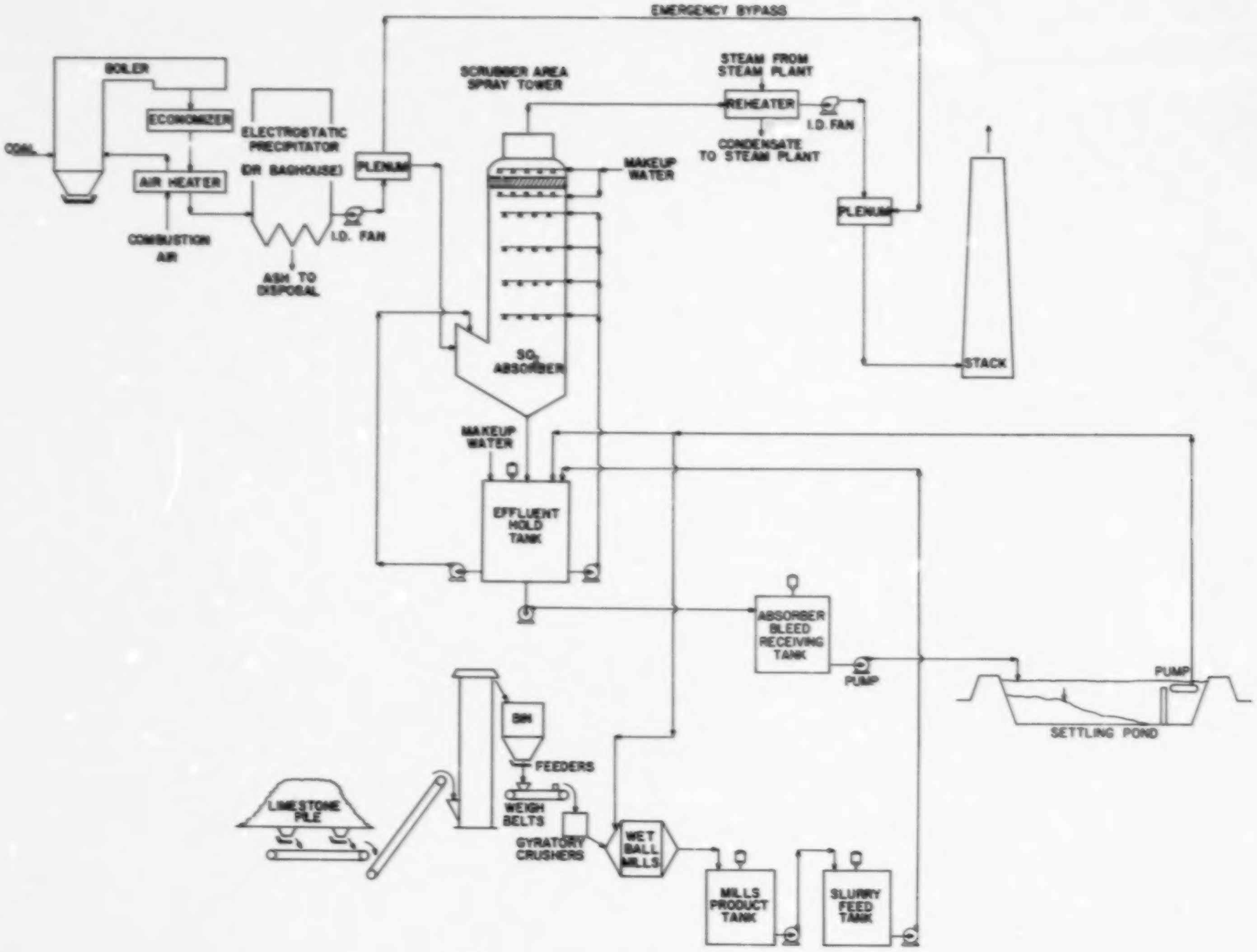
EMERGENCY BYPASS
BOILER
COAL
ECONOMIZER
AIR HEATER
COMBUSTION AIR
ELECTROSTATIC PRECIPITATOR (OR BAGHOUSE)
ASH TO DISPOSAL
I.D. FAN
PLENUM
SCRUBBER AREA SPRAY TOWER
MAKEUP WATER
SO2 ABSORBER
STEAM FROM STEAM PLANT
REHEATER
CONDENSATE TO STEAM PLANT
I.D. FAN
PLENUM
STACK
MAKEUP WATER
EFFLUENT HOLD TANK
ABSORBER BLEED RECEIVING TANK
PUMP
PUMP
SETTLING POND
BIN
FEEDERS
WEIGH BELTS
GYRATORY CRUSHERS
LIMESTONE PILE
WET BALL MILLS
MILLS PRODUCT TANK
SLURRY FEED TANK

Figure 4. Flow diagram for the limestone-scrubbing process.

high bypass levels, reheat is not needed because the bypassed flue gas at 300°F provides sufficient heat when combined with the 127°F scrubbed gas. The reheater consists of an array of steam-heated Inconel 625 (upstream, wet side) and Cor-Ten (downstream, dry side) tubes. Steam from the power plant and bypassed flue gas are used as the heat sources for the reheater.

### Slurry Recirculation--

Makeup limestone slurry from the slurry feed tank and supernate from the waste disposal pond are fed to the effluent hold tanks where they are blended with the slurry draining from the absorbers. Most of the slurry is recirculated from this tank to the spray tower and the presaturator; part of it is withdrawn as a bleedstream and pumped to the waste disposal pond.

### Waste Disposal System--

The FGD program has the capacity to model several waste disposal systems. The system used in this study is the direct ponding method. This system consists of a clay-lined pond one mile from the power plant. The pond is sized for the life of the power plant and is designed to minimize the sum of construction and land costs (the optimum depth-to-area ratio). The waste bleedstream from the absorbers is pumped directly to the pond as a 15% solids slurry where it is assumed to settle to 40% solids. The pond supernate is pumped back for use in the wet ball mills and the absorbers to maintain a closed-loop system.

## ECONOMIC BENEFITS AND PENALTIES PROGRAM

There are certain physical and chemical differences between cleaned coal and the corresponding raw coal, such as lower ash content, higher moisture content, and generally higher heating value. These differences result in a wide range of economic benefits or penalties for a power plant burning cleaned coal. These other benefits and penalties arise from the differences in the costs of (1) coal received at the power plant, (2) power plant operations, (3) flue gas cleaning, and (4) ash collection and disposal. This program calculates these other economic effects of coal cleaning based on data provided by the three previous programs. These benefits and penalties require consideration to accurately evaluate the overall economics of a coal-cleaning process.

The economic benefits and penalties from using cleaned coal can exist in both the design and operation of various segments of the entire power plant. This requires that the capital investment and annual revenue requirements for power generation be adjusted to account for them.

The actual economic benefits and penalties program is relatively simple in comparison with the other programs of the combined model. The processing sequence can be divided into three basic areas: input, processing, and output. The first and third areas simply get data into and out of the program. The processing area calculates the values for the economic benefits and penalties that are considered in the program. The individual benefits or penalties determined by this model fall in one of the four cost subdivisions:

Cost of the FGD process

- FGD capital investment
- FGD annual revenue requirements

Cost of coal received at the power plant

- Raw coal loss
- Transportation costs
- United Mine Workers' (UMW) pension trust
- Coal severance taxes

Cost of power plant operations (exclusive of FGD and waste disposal)

- Coal crushing costs
- Coal pulverization costs
- Power plant maintenance costs
- Power plant availability
- Boiler efficiency

Cost of ash collection and disposal

- Electrostatic precipitator (ESP) costs
- Ash handling and disposal costs

These economic benefits and penalties, as well as the equations used in the model to determine a value for them, are discussed below.

FGD Capital Investment--

The most obvious benefit of coal cleaning is in the reduced FGD requirement. This reduction is a result of the comparatively lower sulfur content and higher heating value of cleaned coal over raw coal which reduces the flue gas flow rate and the scrubbing requirement. These characteristics allow the FGD process to be smaller and the bypass gas stream to be larger for the same emission limit. Both of these factors lead to a lower investment cost for the FGD process.

The actual investment benefit is determined by using the total capital investment values supplied by the FGD programs. The first value is the total capital investment of an FGD process designed to clean the flue gas when raw coal is burned. The second value is the investment required for an FGD process which must clean the flue gas produced by the combustion of cleaned

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coal. The economic benefit of coal cleaning in this area is the difference between the two values.

FGD Annual Revenue Requirement--

In the case of the revenue requirement for the FGD process, it is affected by the same characteristics of coal cleaning as the capital investment. The FGD annual revenue requirement benefit attributable to coal cleaning is due to the reduction in scrubbing slurry rates, waste disposal rates, etc. Both the first-year annual revenue requirement benefit and the levelized annual revenue requirement benefit are found by taking the difference between the costs of the FGD process cleaning the raw coal flue gas and the process cleaning the cleaned coal flue gas.

Raw Coal Loss--

At the present, coal-cleaning technology has not advanced to the point where 100% separation can be achieved between pure coal and its impurities. Also, it is unlikely that any physical coal-cleaning process will reach such a level because of the physical makeup of coal. Such a goal would require that coal be reduced down to molecular size in order to liberate all the mineral constituents from the organic coal matrix. As a result of this, there will always be some coal lost in the cleaning plant refuse, and some minerals will remain in the cleaned coal. The coal which is lost in the refuse must be considered an economic penalty of coal cleaning.

The quantity of pure coal lost in the cleaning plant refuse is calculated (on a Btu basis) in the coal-cleaning program and transferred to the benefits and penalties program. The amount of this penalty is then determined in that program by multiplying the quantity lost times a specified cost per ton. This cost has been set to 20.81 $/ton of coal lost for the cases in this report (1984 dollars). This value represents the incremental mining costs associated with mining the increased tonnage of coal but does not include transportation, UMW pension payments, royalties, sales expenses, etc., because this coal is discarded as refuse. The entire algorithm that is used in the model to calculate this penalty is presented below.

Step 1: $BTUR = F \cdot HVR \cdot 2000$

BTUR = quantity of heat inherent in the raw coal fed to the cleaning plant necessary to produce the quantity of cleaned coal required to meet the power plant heat requirements, Btu/yr

F = quantity of raw coal fed to the cleaning plant necessary to produce the quantity of cleaned coal required to meet the power plant heat requirements, tons/yr

HVR = heating value of the raw coal, Btu/lb, as-received basis

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Step 2: $BTUC = C \cdot HVC \cdot 2000$

BTUC = quantity of heat inherent in the cleaned coal necessary to meet the power plant heat requirements, Btu/yr

C = quantity of cleaned coal required to meet the power plant heat requirement, tons/yr

HVC = heating value of the cleaned coal, Btu/lb, as-received basis

Step 3: $COALL = (BTUR - BTUC)/(2000\ HVR)$

COALL = Btu equivalent quantity of coal lost in the refuse of the cleaning plant, tons/yr

Step 4: $COALP = COALL \cdot RP$

COALP = coal loss penalty of coal cleaning, \$/yr

RP = raw coal unit price, \$/ton

Transportation Costs--

In most cases coal cleaning, when performed at the mine, reduces the coal transportation cost by raising the heating value of the coal. This in effect decreases the amount of coal needed to satisfy the heat requirement of a specific power plant. Although these shipping costs are directly related to the quantity shipped, they are also dependent on the rates, which vary substantially with the shipping method and distance.

Since rail transportation is the most prevalent method of coal transportation (7), it is used to determine the effect of coal cleaning on shipping costs. The development of a formula that will accurately estimate rail transportation costs is difficult because most rate schedules are negotiated individually between the shipper and receiver. These conditions impose obvious limitations on any equation used to predict coal transportation rates by rail or by any other method. The equation used by the program is derived from an analysis of 680-unit train and carload rates for U.S. origin - U.S. destination pairs in 1976 (7). The equation, adjusted to reflect 1984 conditions, is derived below:

$C = 258d^{-0.41}$

C = freight cost, mills/ton-mile in 1984 dollars

d = user-supplied distance from the coal-cleaning plant to the power plant, miles

To assess the overall benefit of coal cleaning, this equation is converted to a unit cost.

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$UC = 0.258d^{0.59}$

UC = unit freight cost, \$/ton of coal shipped

The actual benefit from coal cleaning can be determined from this unit cost by subtracting the total cost of shipping cleaned coal from the total cost of shipping raw coal that would meet the same power plant heat requirement.

$TC = UC\ (R - C)$

TC = annual transportation cost benefit of coal cleaning, \$/yr

R = quantity of raw coal required to meet the power plant heat requirement, tons/yr

UMW Pension Trust--

The provisions of the 1978 UMW contract require mine operators to pay \$1.385 to the Pensions and Benefit Trust Fund for every ton of coal that is shipped to a consumer (7). As with transportation costs, cleaned coal usually has a higher heating value than raw coal, which leads to a lower coal requirement for cleaned coal than raw coal for a particular power plant heat requirement. This yields a saving for the mine operators by decreasing the contributions required to the trust fund. The equation for this saving, adjusted to reflect 1984 conditions, is given below:

$FC = 2.079\ (R - C)$

FC = annual saving on trust fund contribution from coal cleaning, \$/yr

Coal Severance Taxes--

State-imposed coal taxes, usually called severance taxes, are often levied by the State governments on coal production within their boundaries. As shown in Table 4, these taxes are based on either: (1) the tonnage of coal shipped, (2) the tonnage of coal mined, (3) the value of coal shipped, or (4) the value of coal mined. The tonnage-related taxes ranged in 1980 from 0.2¢/ton to over 90¢/ton, while the value-related taxes ranged from 2% to 30% of the selling price (14).

The effect of coal cleaning on these severance taxes can either be a cost benefit or a penalty, depending upon the method of taxation. If the taxes are levied on the tonnage of coal shipped, coal cleaning would usually yield an economic benefit by reducing the number of tons shipped. On the other hand, if the taxes are levied on the tonnage or value of the coal as mined, coal cleaning would result in an economic penalty because more coal must be mined to make up the loss of the heating value of the coal in the coal-cleaning refuse. If the coal taxes are based on the value of the coal shipped, coal cleaning can yield an economic benefit or penalty, depending on the unit prices of the clean and raw coals. Each of these cases can be illustrated by an equation.

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TABLE 4. STATE-IMPOSED COAL TAXES AS OF SEPTEMBER 30, 1980

| Name | State | Rate |
|---|---|---|
| Severance tax | Alabama | 33.5¢/ton (plus 50¢/ton additional in DeKalb County) |
| Mining license tax | Alaska | Net income from mining property at following rates:<br>$40,000 to $50,000 - 3%<br>$50,001 to $100,000 - $1,500 plus 5% of excess over $50,000<br>$100,000 or over - $4,000 plus 7% of excess over $100,000<br>(Alaska allows depletion as a deduction.) |
| Severance tax | Arkansas | 2¢/ton |
| Coal tonnage tax | Colorado | 60¢/ton (surface mined), 30¢/ton (deep mined), increasing 1% for each 3-point increase in wholesale price index (effective January 1, 1978). 0.738 $/ton on surface coal as of September 1980. |
| Severance tax | Idaho | 2% of net value mined (Idaho allows as a deduction) |
| Severance tax | Kentucky | 4-1/2% of gross income with a 50¢/ton floor |
| Coal mine operators tax | Montana | |

| Heating quality, Btu/lb of coal | Surface | Underground |
|---|---|---|
| Under 7,000 | 12¢ or 20% of value | 5¢ or 3% of value |
| 7,000-8,000 | 22¢ or 30% of value | 8¢ or 4% of value |
| 8,000-9,000 | 34¢ or 30% of value | 10¢ or 4% of value |
| Over 9,000 | 40¢ or 30% of value | 12¢ or 4% of value |

(Continued)

TABLE 4. (Continued)

| Name | State | Rate |
|---|---|---|
| Severance tax | New Mexico | Effective July 1, 1977. Tax is 38¢/ton on steam coal and 18¢/ton metallurgical coal. A surtax amounting to the percentage increase in the consumer price index attaches effective July 1, 1978, i.e., assume CPI increase of 6% from 1976 to 1977. New rate July 1, 1978, would be 40¢/ton (38¢ x 1.06 = $0.4028). The resources excise tax at 0.75% and conservation tax at 0.18% remained unchanged. |
| Severance tax | North Dakota | $0.85/ton, escalating 1¢/ton for each 4-point increase in the wholesale price index from base wholesale price index of July 1, 1979. In lieu of all other taxes on coal. On July 1, 1980, it was $0.93/ton. |
| Severance tax | Ohio | 4¢/ton |
| Severance tax | Tennessee | 20¢/ton |
| Occupation tax | West Virginia | 3.85% of gross income |
| Mining severance tax | Wyoming | 17% including ad valorem |

Source: Reference 14.

EPA Form 2350-4 (4-80)

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Case 1: Tax based on tonnage of coal shipped

$TB = TR (R - C)$

TB = tax benefit of coal cleaning, \$/yr

TR = tax rate on coal shipped, \$/ton

Case 2: Tax based on tonnage of coal mined

$TB = TR (R - F)$

TB = tax benefit (a negative value indicates a penalty) of coal cleaning, \$/yr

Case 3: Tax based on the value of coal shipped

$TB = TR [RP(R) - CP(C)]$

TB = tax benefit (negative value indicates a penalty) of coal cleaning, \$/yr

CP = clean coal unit price, \$/ton

Case 4: Tax based on the value of the coal mined

$TB = TR (RP)(R - F)$

Any of the four equations can be used. In the illustrative examples in this report, case 1, with a tax rate of 0.50 \$/ton is used (this is the Kentucky tax rate and is about average).

Coal Crushing Costs--

For pulverized coal boilers, coal crushing is a 2-stage process designed to accomplish a particular objective at each stage, first to reduce run-of-mine (ROM) coal to sizes which can be sold or cleaned in a coal-cleaning plant, and second to further reduce the coal to a particle size that can be fed to the power plant pulverizers (the model does not include cyclone-burner boilers). The first objective is usually accomplished at the coal-cleaning plant; therefore, the capital and operating costs are included as part of the coal-cleaning costs and are not considered as independent benefits or penalties. However, the second objective is accomplished at the power plant, and the effect of coal cleaning on the costs in this case must be considered as a benefit or penalty as the case warrants.

The factors influencing coal crushing costs include the magnitude of the size reduction required, the features of the size-reduction equipment, and certain properties of the feed coal. Except for the equipment features, coal cleaning significantly alters these factors, and as a result, alters the crushing costs.

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PAGE NUMBER
EPA Form 2350-4 (4-80)

Coal cleaning reduces the magnitude of crushing required at the power plant in two ways. First, the increased heating value of cleaned coal can either increase capacity (in terms of Btu/hr) of an existing crusher or reduce the size of a new crusher by decreasing the quantity of coal to be crushed. Second, the coal-cleaning process will generally produce coal with a much smaller topsize than ROM coal, in which case a portion of the required size reduction has already been done. To estimate the effect of coal cleaning on crushing costs, the program calculates comparative capital investments for the power plant crushers when crushing raw and cleaned coals. A stepwise procedure is used to determine the capital investment for single-roll crushers, which are typical power plant secondary size-reduction devices.

Step 1: $TPH = CR/NC$

$TPH$ = coal feed rate to one crusher, tons/hr

$CR$ = total coal feed rate to the power plant, tons/hr

$NC$ = number of crushers per boiler (dependent on boiler size)

Step 2: $HP = 0.0841(TPH)(Wi)[(1/Dp)^{0.5} - (1-Df)^{0.5}]$ Ref. (15)

$HP$ = motor size required to drive a single-roll crusher, in horsepower

$Wi$ = work index for crushing coal, kWh/ton

$Dp$ = maximum size of crusher product, inches

$Df$ = maximum size of crusher feed, inches

Step 3: $CSRC = 4569(HP)^{0.76}$ Ref. (16)

$CSRC$ = cost of a single-roll crusher, 1977 dollars

Step 4: $PC = (CSRC)(NC)(MINDEX/204.1)$

$PC$ = total process capital for the crushers

$MINDEX$ = material cost scaling index to convert from 1977 dollars to desired present value

Step 5: $TCI = PC + SE + IC + OC + WC$

$TCI$ = total capital investment of the crushers

$SE$ = services, utilities, and miscellaneous
= $0.06(PC)$, as a standard value for the program

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3/8"
PAGE NUMBER
EPA Form 2350-4 (4-80)

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IC = indirect investment
$= 0.43(PC + SE)$, as a standard value for the program

OC = other capital charges
$= 0.236(PC + SE + IC)$, as a standard value for the program

WC = working capital
$= (1.5/12)(\text{total power cost}) + 0.03\,(PC + SE)$

The actual benefit is determined by taking the difference between the crusher capital investments for raw and cleaned coal.

Coal cleaning alters some physical characteristics of the coal, which also creates benefits in the operating costs of the power plant crushers. One of these properties includes the coal abrasiveness, which is directly related to the maintenance costs. Coal cleaning reduces the abrasiveness by reducing the mineral matter in the coal. This has been supported by an analysis of TVA maintenance records (17), and is included in the general maintenance section discussed later in this report. The following stepwise procedure is used to determine the effect of other crushing-related benefits, resulting from the use of cleaned coal, on the power plant operating costs.

Step 1: $P = 0.746(HP)(OT)(PC)(NC)$

P = total annual electricity cost to operate crushers

HP = maximum motor size required to drive a single-roll crusher, horsepower

OT = onstream time, hr/yr

PC = cost of electricity, $/kWh

NC = number of crushers required per boiler (dependent on boiler size)

Step 2: $ARR = (P) + (CC)(TCI)$

ARR = annual revenue requirement

CC = capital charges factor
$= 0.147$, as a standard value for the program

As was the case with the capital investment benefit, the annual revenue requirements benefit is determined by the difference between the crusher operating costs for raw and cleaned coal. Only the areas that change with the coal characteristics are considered in this value. For the illustrative examples in this report, a raw coal topsize of 4 inches versus a cleaned coal topsize of 3 inches and 10 single-roll crushers serving 10 pulverizers are used.

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Coal Pulverization Costs--

Coal pulverization, the process of reducing the coal that is fed to the power plant to a very small particle size, is the second comminution process affected by coal cleaning. These effects are essentially the same as those for the crusher; however, there is one notable difference created by the increased surface moisture of clean coal over that in raw coal. Large amounts of surface moisture can cause slippage of the grinding elements and produce agglomerations of the fines in the pulverizer. Consequently, mill capacity is reduced because fines are not removed as quickly as they would be with coal that has a low surface moisture. Generally the effect of surface moisture on mill capacity varies greatly among types of mills but the effect is to decrease mill capacity at a high level of surface moisture.

In order to quantify the benefit or penalty of coal cleaning on pulverization costs, the capital investment and operating costs must be treated separately, as was the case with the crushing costs. The following procedure is used to determine the capital investment for the power plant coal pulverizers from which the capital investment benefit can be calculated.

Step 1: $P = 0.746(Wi)(CR)/NP$ Ref. (18)

$P$ = pulverizer power requirement, kW

$Wi$ = work index for pulverizing coal, hp-hr/ton
= 22.4, as a standard value for the program

$CR$ = coal flow rate, tons/hr

$NP$ = number of pulverizers per boiler (dependent on boiler size)

Step 2: $SPC = BC(P/BP)^n$ Ref. (19)

$SPC$ = total process capital cost of the pulverizer, 1980 dollars

$BC$ = total process capital cost of the base pulverizer, 1980 dollars
= $586,300, as a standard value for the program

$P$ = pulverizer power requirement, kW

$BP$ = base pulverizer power requirement, kW
= 450, as a standard value for the program

$n$ = scaling exponent
= 0.90, as a standard value for the program (if $P > 200$)
= 0.75, as a standard value for the program (if $P \leq 200$)

Step 3: $PC = (MINDEX/257.8)(NP)(SPC)$

$PC$ = total process capital for all pulverizers

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EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 267)

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Step 4: $TCI = PC + SE + IC + OC + WC$

TCI = total capital investment of the pulverizers

SE = services, utilities, and miscellaneous
= 0.06(PC), as a standard value for the program

IC = indirect investment
= 0.43(PC + SE), as a standard value for the program

OC = other capital charges
= 0.236(PC + SE + IC), as a standard value for the program

WC = working capital
= (1.5/12)(total electricity cost) + 0.03(PC + SE)

The primary effects of coal cleaning on the operating costs of the pulverizers occur in three areas: (1) the change in pulverizer maintenance costs which can be attributed to changes in the characteristics and quantity of the coal, (2) the change in pulverizer power requirement, and (3) the change in capital charges which results from any change in the capital investment of the pulverizers. The first element is included in the general maintenance section discussed later, but the last two are determined by the following 2-step procedure. It is used to determine the annual revenue requirements benefit in the pulverization area that can be attributed to coal cleaning.

Step 1: $PC = (P)(OT)(CP)(NP)$

PC = total annual electricity cost to operate pulverizers, \$/yr

P = pulverizer power requirement, kW

OT = onstream time, hr/yr

CP = cost of electric power, \$/kWh

Step 2: $ARR = PC + (CC)TCI$

ARR = annual revenue requirement, \$/yr

CC = capital charges factor, decimal
= 0.147, as a standard value for the program

The actual benefits or penalties in the pulverization costs are determined by taking the differences between the respective costs for pulverizing raw and cleaned coal. Examples of the results of these procedures are illustrated in the base case printout included in the appendix. Note, however, that the benefits or penalties for the pulverizing and crushing operations are combined to form the grinding section of the benefits/penalties

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summary table. Again, it should also be noted that only the areas that change as a result of a change in coal characteristics are considered in this value.

Power Plant Maintenance Costs--

The quality and quantity of the coal that is fed to a power plant can have a distinct effect on the general maintenance costs of various types of equipment. In addition to the equipment areas previously discussed, which are included in the values calculated here, other areas that are affected include the boilers and accessories, coal conveying and storage equipment, air heaters, and many other types of equipment. Since coal cleaning affects both the composition and amount of coal burned by the power plant, it obviously has an effect on the maintenance costs of the power plant.

Studies have been made using data from TVA power plants to determine correlations between coal quality and many elements of power plant maintenance costs (17,20). Selected data from these studies have been used to develop an equation to determine the fuel-related maintenance costs affected by coal cleaning.

$$\mathrm{Ln}(M) = [12.59 + (0.00434A + 0.00955S)(CR/1000)]PINDEX/218.8 \quad \text{Ref. (20)}$$

$M$ = fuel-related maintenance costs

$A$ = weight fraction of ash in coal, as-received basis

$S$ = weight fraction of sulfur in coal, as-received basis

$CR$ = coal flow rate, tons/yr

$PINDEX$ = plant cost scaling index to convert to dollars in desired present value (see Premises)

The benefit or penalty is determined by comparing the cost obtained when using the values for the raw coal with the cost obtained using the values for cleaned coal.

Power Plant Availability--

Power plant boiler availability is affected by many factors, many of which are not influenced by coal composition. However, some of these factors such as tube corrosion, sootblower failure, slagging, and fouling are definitely affected by changes in the mineral content of the coal used. It is difficult, however, to quantify the influences of coal cleaning on availability because the factors unrelated to fuel mask the effects of the fuel-related ones. In an attempt to quantify these influences, the information that was used to develop the previously discussed maintenance relationship has also been used to analyze the effect of coal quality on boiler availability (20). In order to develop a relationship that would model this effect, it was necessary to relate availability to the time the boiler is out of service because of coal-related problems. This is done in the following algorithm by

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

assuming that every hour the boiler is forced out of service is an hour of lost availability.

Step 1: $\mathrm{Ln}(AL) = 3.164 + 0.032A + 0.293S + 2.176\ \mathrm{Ln}[2.45 + \mathrm{Arctan}(Age - 18.8)/8.1]^*$ Ref. (20)

AL = availability lost as a result of forced outages caused by coal-related problems, hr/yr

Age = power plant age, yrs

*Note: [(Age - 18.8)/8.1] has the units of radians

Step 2: $AC = (AL)(MW)(PC)(1000)$

AC = total cost of availability lost as a result of forced outages caused by coal-related problems, \$/yr

MW = power plant capacity, megawatts

PC = current cost of replacement power, \$/kWh

The benefit or penalty attributable to coal cleaning is determined by taking the difference between the cost of availability lost when using raw coal and the cost obtained when using cleaned coal.

Boiler Efficiency--

Another factor of power plant operations that is influenced by coal cleaning is the boiler efficiency. It is affected by the quality of the coal burned in much the same manner as availability with one notable exception. This exception is due to the negative impact that the increased moisture, inherent in cleaned coal, has on efficiency. To be more specific, tube fouling and slagging are reduced by the lower mineral content in cleaned coal, and this leads to better heat transfer with a corresponding increase in efficiency. On the other hand, the increase in moisture content decreases the boiler efficiency by increasing the amount of water to be vaporized.

The data used to develop the relationships for the effect of coal cleaning on power plant maintenance and availability have also been used to derive a relationship for boiler efficiency. The basis for this relationship is an assumption that efficiency can be measured by the amount of heat required to generate one kilowatt hour of power. This assumption is used in the algorithm presented below.

Step 1: $BR = 91.06 - 0.022\ AR - 0.1MR - 0.039(Age)$ Ref. (20)

BR = boiler efficiency when raw coal is burned

AR = ash content of raw coal, weight percent, as-received basis

MR = moisture content of raw coal, weight percent, as-received basis

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Step 2: $BC = 91.06 - 0.022\ AC - 0.1MC - 0.039(Age)$

$BC$ = boiler efficiency when cleaned coal is burned, percent

$AC$ = ash content of cleaned coal, weight percent, as-received basis

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$MC$ = moisture content of cleaned coal, weight percent, as-received basis

Step 3: $BTUC = BTUR(BR/BC)$

$BTUC$ = boiler heat rate when cleaned coal is burned, Btu/kWh

$BTUR$ = boiler heat rate when raw coal is burned, Btu/kWh
= 9,200 Btu/kWh, as standard value for the program

As can be seen by analyzing the above algorithm, it does not produce a direct cost value for this benefit (or penalty, as the case may be). Instead, it indirectly affects the costs of the power plant and the FGD process by altering the boiler heat rate. For this reason, this effect of coal cleaning is not addressed in the benefits and penalties program, but it is calculated in the coal-cleaning program. This is necessary in order to determine the flow rates for the coal-cleaning process as well as the size of the FGD process that is needed when cleaned coal is burned.

Other Power Plant Operating Factors--

The previously mentioned plant operating factors, such as maintenance and availability, are not the only ones affected by the quality of coal burned. Other factors, such as rated capacity and peaking capacity, are also affected, but the information available is of questionable reliability. For this reason, they have been omitted from the present model. Should information become available in the future, it would be easy to revise the benefits and penalties program to include the more accurate data.

ESP Costs--

Fly ash removal from the combustion gases generated in the power plant is usually accomplished with ESPs situated just after the air heaters. The major factors affecting the size and cost of an ESP are the specific collection area (SCA), which is primarily determined by the resistivity of the fly ash and volumetric flow rate of flue gas. For a specific type of ESP design, fly ash resistivity can be related to such coal characteristics as the sulfur content, the ash content, and ash composition. The volumetric flow rate of flue gas to the ESP is directly related to coal composition. Since such factors influence the size of the ESP, it is apparent that coal cleaning will affect the ESP cost. The cost values obtained are usually negative, meaning that coal cleaning produces a penalty on ESP costs. This is primarily due to the detrimental effect of lower sulfur on the fly ash resistivity.

Determination of the capital investment is a stepwise procedure.

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PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
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**Step 1:** $UR = (1)(10^6)(A)(E/HHV)$ Ref. (21)

$UR$ = uncontrolled fly ash emission rate, lb/$10^6$ Btu

$A$ = weight fraction of ash in coal, as-received basis

$E$ = user-supplied fly ash emission factor, decimal

$HHV$ = heating value of coal, Btu/lb, as-received basis

**Step 2:** $Nc = (UR - CR)/UR$

$Nc$ = fly ash collection efficiency, fraction by weight

$CR$ = allowable fly ash emission rate from the ESP, lb/$10^6$ Btu

**Step 3:** $Wce = -D + 0.01j - 0.18P + 0.018V + 0.01Ne + 0.35M + 0.06e^{50S}$
$-1.1 \times 10^{-4} - 2.47(UR \cdot HB/Q) - 0.2A$

$Wce$ = particle migration velocity, ft/sec

$D$ = a constant dependent on boiler type, ft/sec
= 0.54, for pulverized-coal-fired boilers, as a standard value for the program

$j$ = current density, uA/$ft^2$
= 17.7, for coal with sulfur content >1.0 wt %, as received
= 4.0, for coal with sulfur content ≤1.0 wt %, as received

$P$ = power density, W/$ft^2$
= 0.65, for coal with sulfur content >1.0 wt %, as received
= 0.12, for coal with sulfur content ≤1.0 wt %, as received

$V$ = voltage, kV
= 36.7, for coal with sulfur content >1.0 wt %, as received
= 30.0, for coal with sulfur content ≤1.0 wt %, as received

$Ne$ = number of electrical sets
= 7.9, as a standard value for the program

$M$ = weight fraction of water in coal

$S$ = weight fraction of sulfur in coal, as-received basis

$T$ = user-supplied flue gas temperature, °F

$HB$ = rate of heat input to boiler, $10^6$ Btu/hr
= (HHV)(coal-firing rate, lb/hr)/$10^6$

$Q$ = flue gas flow rate, a$ft^3$/min

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

**Step 4:** Acp = -0.0167Q[1n(1 - Nc)/Wce]

Acp = collecting electrode area, $ft^2$

**Step 5:** SCA = (Acp)(1 x 103)(S/Q) Ref. (22)

SCA = specific collection area, $ft^2/kaft^3/min$

S = design safety factor
= 1.25, as a standard value for the program

**Step 6:** PC = $(PC^1)\ (Q/Q^1)^q\ (SCA/SCA^1)^s$

PC = total process capital for the ESP

$PC^1$ = total process capital for the base ESP
= 13,400,000, as a standard value for the program

$Q^1$ = flue gas flow rate for base ESP, $aft^3/min$
= $1.97 \times 10^6$, as a standard value for the program

q = 0.93, for cold-side ESP, as a standard value for the program

$SCA^1$ = specific collection area for base ESP, $ft^2/103\ aft^3/min$
= 350, as a standard value for the program

s = 0.6, for cold-side ESP, as a standard value for the program

**Step 7:** TCI = PC + SE + IC + OC + LC + WC

TCI = total capital investment of ESP

SE = services, utilities, and miscellaneous
= 0.06(PC), as a standard value for the program

IC = indirect investment
= 0.43(PC + SE), as a standard value for the program

OC = other capital charges
= 0.236(PC + SE + IC), as a standard value for the program

LC = land cost

WC = working capital
= 0.03(PC + SE) + (1.5/12)(total conversion cost) + (1.5/12) (plant and administrative overhead), as a standard value for the program

The actual benefit or penalty is found by comparing the capital investment costs for the ESP when raw and cleaned coal are used.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

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The primary effect of coal cleaning on the operating costs of the ESP is due to the change in the ESP size resulting from the use of cleaned coal as opposed to raw coal. The major elements of the annual revenue requirements for an ESP which change with ESP size are determined in the following stepwise procedure.

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Step 1: $FPCc = (5.87 \times 10^{-5})(Q \cdot AH \cdot PC/Ef)$ Ref. (21)

$FPCc$ = ID fan power cost attributable to ESP, \$/yr

$AH$ = onstream time, hr/yr

$PC$ = cost of electrical power, \$/kWh

$Ef$ = efficiency of ID fan, decimal
= 0.75, as a standard value of the program

Step 2: $EPCc = 10^{-3}(PC)(AH)(P)(Acp/Ntr)$

$EPCc$ = annual power cost to maintain the electrostatic field, \$/yr

$P$ = power density, W/ft$^2$
= 0.65, for coal with sulfur content >1.0 wt %, as received
= 0.12, for coal with sulfur content ≤1.0 wt %, as received

$Acp$ = collecting electrode area, ft$^2$

$Ntr$ = transformer-rectifier efficiency, decimal
= 0.65, as a standard value for the program

Step 3: $OLc = 14.434\ Acp^{0.50} \cdot AWF$

$OLc$ = annual direct operating labor cost, \$/yr

$AWF$ = annual wage escalation factor relative to 7.41 \$/hr
= (15.00/7.41), to convert to 1984 dollars

Step 4: $MLc = 0.67(Acp^{0.786})AWF$

$MLc$ = ESP annual direct maintenance labor, \$/yr

Step 5: $MMc = 6.31(10^{-2}Acp)(AMF)$

$MMc$ = ESP annual maintenance material cost, \$/yr

$AMF$ = annual material escalation factor
= (388.4/240.6), to convert to 1984 dollars

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3/8"
PAGE NUMBER

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
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Step 6: $TCC = FPCc + EPCc + OLc + MLc + MMc$

$TCC$ = total conversion costs, \$/yr

Step 7: $OC = 0.6(OLc + MLc + MMc)$

$OC$ = plant and administrative overhead costs, \$/yr

Step 8: $CC = 0.147TCI$

$CC$ = levelized capital charges, \$/yr

$TCI$ = total capital investment

Step 9: $ARR = TCC + OC + CC$

$ARR$ = total first-year annual revenue requirements, \$/yr

An ESP is not the only device that is used by the utility industry to remove flue gas particulates, but it is the most common. Other equipment such as baghouses are also being used, however. Coal cleaning would definitely have a beneficial cost effect on baghouses because of the reduced ash content of cleaned coal and the lower coal-firing rate. This differs from the economic penalty in ESP costs caused by coal cleaning. The present benefits and penalties program only includes estimates for ESP costs but should future considerations warrant it, estimates for baghouse costs could easily be added.

Ash Handling and Disposal Costs--

The quantity of fly ash and bottom ash generated at a power plant is the principle controlling element of the ash handling and disposal costs for the plant. Coal cleaning reduces the amount of ash by producing coal with an ash content lower than that in the raw coal, and by increasing the heating value of the coal, thus reducing the quantity of coal necessary to meet the power plant heat requirement.

The economic benefits in the ash handling and disposal areas resulting from the use of cleaned coal are expressed in much the same way as many of the previous benefits and penalties; by comparing the capital investments and annual revenue requirements for ash handling and the disposal areas when raw coal is burned with the respective costs for the case when cleaned coal is burned. These costs have been evaluated by Kennedy, et al. (23), from which the following equations were derived.

$TCI = 4068(AG)^{0.68}$ Ref. (23)

$TCI$ = total capital investment

$AG$ = total ash generated, tons/yr

$$ARR = 2034(AG)^{0.64}$$

ARR = annual revenue requirements, \$/yr

These equations are used to determine the economic benefit of coal cleaning in the ash handling and ash disposal areas.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
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# DESIGN AND ECONOMIC PREMISES FOR MODEL USE

The premises used as the bases for this model were developed by TVA in conjunction with EPA, the Electric Power Research Institute (EPRI), and others for economic evaluations of utility emission control processes. The power plant and FGD design and economic premises have been used by TVA in previous economic studies (13,23). Those defining the coal-cleaning plant design and operating conditions are based on a previous coal-cleaning study conducted by TVA (1) and on industry information. The premises for the economic benefits and penalties program were developed specifically for the combined coal-cleaning - FGD model. They are based on published information and TVA studies of the effects of coal properties on power plant operation (17,20,24).

The base case conditions assume a new, midwestern, 1,000-MW, pulverized-coal-fired power plant supplied by a mine-mouth coal-cleaning plant 500 miles away, with transportation by unit train. The power plant is assumed to operate at full load for 5,500 hr/yr for 30 years. The coal-cleaning process inocrporates a dense-medium vessel for coarse coal, dense-medium cyclones for intermediate coal, and froth flotation for fine coal. A wet/limestone-scrubbing process with pond disposal of the waste is used for the FGD process.

The economic premises are based on regulated utility economics. Capital investments, first-year annual revenue requirements, and levelized annual revenue requirements for the coal-cleaning plant and the FGD system are defined. Costs are based on 1982 dollars for the capital investment and 1984 dollars for the annual revenue requirements.

## STUDY DESIGN PREMISES

### Coal Premises

The coals consist of four eastern (Appalachian or eastern Central Basin) bituminous coals, one each from the Illinois No. 6, Pittsburgh, Upper Freeport, and Cedar Grove seams. The base case coal for the example runs in this report is the Pittsburgh coal. The compositions of these coals are summarized in Table 5 on an as-received basis, and the washability data are presented in Tables A-1 through A-4. The coals are supplied in 4-inch topsize after large rocks, trash, and mine timbers have been removed and ROM coal is passed through a rotary breaker and past a tramp iron magnet.

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3/8"

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
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TABLE 5. COMPOSITIONS OF PREMISE COALS, AS-RECEIVED BASIS

| Coal | Sulfur Total, % | Sulfur Pyritic, % | Sulfur Organic, % | Moisture, % | Ash, % |
|---|---|---|---|---|---|
| Illinois No. 6 seam | 4.34 | 3.27 | 1.07 | 1.36 | 29.39 |
| Pittsburgh seam | 3.67 | 2.15 | 1.52 | 3.42 | 13.81 |
| Upper Freeport seam | 2.32 | 1.88 | 0.44 | 5.60 | 16.80 |
| Cedar Grove seam | 0.85 | N.A. | 0.85 | 6.60 | 16.04 |

| Coal | Heat content, Btu/lb | Proximate and ultimate analyses M, % | FC, % | C, % | H, % | O, % | N, % | Cl, % |
|---|---|---|---|---|---|---|---|---|
| Illinois No. 6 seam | 9,667 | 31.96 | 37.29 | 53.32 | 3.71 | 6.65 | 1.12 | 0.10 |
| Pittsburgh seam | 12,121 | 35.83 | 46.94 | 65.35 | 4.42 | 7.87 | 1.35 | 0.10 |
| Upper Freeport seam | 11,668 | 29.45 | 48.15 | 62.69 | 4.08 | 7.10 | 1.30 | 0.10 |
| Cedar Grove seam | 11,680 | N.A. | N.A. | 66.29 | 4.24 | 4.65 | 1.23 | 0.10 |

N.A. - not available.

## Coal-Cleaning Plant

The coal-cleaning plant is located at the mine and is designed to supply the coal demand of the specified power plant. The plant is based on 5,500 hr/yr of operation, has a 3-day raw coal and a 7-day cleaned coal storage capacity, closed water circuits, and waste disposal in a landfill one mile from the plant.

The coal-cleaning plant uses physical coal-cleaning techniques that represent current commercial technology for high-efficiency physical coal cleaning. Coal entering the plant is crushed and screened into three size fractions. The primary separation mechanism is a dense-medium vessel for the coarse coal, a dense-medium cyclone for the intermediate coal, and froth flotation for the fine size fraction. Associated equipment includes screens, sieve bends, centrifuges, and filters. All the equipment used is based on commercially available designs.

The cleaning performance of the process is determined by the washability of the coal, as determined by standard laboratory washability tests (7,25). These tests determine the quantity and chemical and physical properties of the sink and float fractions of a sized coal sample over a range of specific gravities using organic separation liquids. The data are correlated to the performance characteristics of the specific cleaning equipment at the specific gravity used to calculate the quantities and properties of the cleaned coal. The quantities and properties of the combined product are calculated from these data. Although it is assumed that there is an optimum specific gravity of separation for each coal, 1.60 is used as the base case value.

## Power Plant Design

A new, single pulverized-coal-fired boiler with a 1,000-MW net electrical output is used for the base case, but the model can simulate various boiler sizes. The design heat rate of the boiler is 9,200 Btu/kWh when raw coal is burned, and it operates at full capacity for 5,500 hr/yr. The power plant life is assumed to be 30 years, representing a total of 165,000 hours of operation during the life of the plant. The flue gas composition is calculated from the coal composition, assuming 20% excess air to the boiler and 19% inleakage in the air heater. It is assumed that 80% of the ash and 92% of the sulfur in the coal are emitted in the flue gas. The sulfur in the flue gas is 97% $SO_2$ and 3% $SO_3$.

## Emission Standards

Most states now have a state implementation plan (SIP) setting individual power plant emission limits, depending in part on the atmospheric sensitivity at the plant location. The emission limits used in this study to represent these limits are 0.6, 1.2, 2.0, and 4.0 lb $SO_2$/MBtu to the boiler.

The program also includes the new source performance standards (NSPS) established by EPA in 1979 (26). These NSPS specify a maximum $SO_2$ emission based on heat input of 1.2 lb $SO_2$/MBtu. In addition to meeting the maximum emission, the 1979 NSPS also require that new plants must reduce the uncontrolled $SO_2$ emissions from 70% to 90%, depending on the uncontrolled $SO_2$ emission level of the raw coal, i.e., the emission reduction achieved by coal cleaning and the sulfur removed with the ash are included as part of the total reduction required.

## FGD System

The FGD process is one of several variants of wet-limestone and lime processes in the model. Upstream fly ash removal to meet the required emission level is assumed and fly ash removal and disposal costs are not included in the FGD system costs, but are accounted for in the benefits and penalties program. The FGD system consists of a plenum into which the power plant ducts discharge and which supplies parallel trains of absorbers with indirect steam reheat to provide a final flue gas stack temperature of 175°F. A booster fan in each train compensates for the FGD system pressure drop. The trains discharge to the stack plenum, which is not included in the FGD costs. A single limestone preparation area consisting of receiving, handling, and ball milling equipment supplies the absorbers.

The absorbers are designed to remove 90% of the $SO_2$ in the flue gas regardless of the $SO_2$ content or emission level required. (It is assumed

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that 50% of the $SO_3$, 95% of the HCl, and 50% of the remaining fly ash are also removed.) The $SO_2$ content of the flue gas and the emission limit determine the quantity of flue gas scrubbed and the size of absorber trains used. Flue gas not scrubbed is bypassed and combined with the scrubbed flue gas in the stack plenum to reduce the amount of reheat needed. Two emergency bypass ducts are provided for 50% of the scrubbed gas. These ducts also serve as the bypass ducts for partial scrubbing. The maximum absorber size is 125 MW or 513,000 $sft^3$/min (60°F). Spare trains are provided on the basis of an 85% availability. The 1,000-MW base case FGD system has eight operating and two spare trains for full scrubbing.

The waste effluent withdrawn from the absorber circulation system is pumped to a disposal pond located one mile from the plant site. The disposal area is an earthen-diked, clay-lined pond designed to minimize the sum of land and construction cost and sized for the life of the project (30 years for the base case). Pond cost includes a 6-foot security fence around the perimeter dike, security lighting, a topsoil storage area, and groundwater monitoring wells.

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## ECONOMIC PREMISES

The economic premises are based on regulated utility economics. They provide for the determination of capital investment, first-year annual revenue requirements, and levelized annual revenue requirements. The FGD costs determined are the installation and operating costs of the systems being evaluated, without consideration of other costs, such as those associated with power plant operation or fly ash removal. It is assumed, for example, that the FGD system does not affect power plant operation. In the case of coal cleaning, however, there is a wide range of economic effects on various elements of power plant operations. In the case of new plants, such as the ones assumed for this project, both the design and operating costs may be affected. To account for these in the overall cost of coal cleaning to the utility, these effects must be individually quantified as either an economic benefit or penalty, which results from the use of cleaned coal instead of the corresponding raw coal from which it comes. In the model, the economic benefits are incremental cost reductions to the capital investments or revenue requirements which may be used to offset the cost of coal cleaning. On the other hand, any economic penalties are cost increases (negative benefits) which provide incremental increases in the costs of power generated due to the use of cleaned coal. The background of these benefits and penalties was presented in an earlier section of this report, but the premises on which they are based are presented in this section.

### Capital Investment

Capital investment estimates for this study represent projects with a 3-year construction period, beginning in early 1981 and ending in late 1983. Capital costs for fixed assets are projected to mid-1982, which represents the midpoint of the construction expenditures schedule.

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**Direct Capital Investments--**

Direct investment costs are prepared using Chemical Engineering cost indexes and projections as shown in Table 6.

TABLE 6. COST INDEXES

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1978 | 1979$^a$ | 1980$^a$ | 1981$^a$ | 1982$^a$ | 1983$^a$ | 1984$^a$ |
| Plant | 218.8 | 240.2 | 259.4 | 278.9 | 299.8 | 322.3 | 344.9 |
| Material$^b$ | 240.6 | 262.5 | 286.1 | 309.0 | 333.7 | 360.4 | 385.6 |
| Labor$^c$ | 185.9 | 209.7 | 226.5 | 244.6 | 264.2 | 285.3 | 305.3 |

a. TVA projections.
b. Same as index in Chemical Engineering for equipment, machinery, supports.
c. Same as index in Chemical Engineering for construction labor.

The direct investments for the two processes comprising this model are determined by two entirely different procedures. In the case of the coal-cleaning plant, the direct investment is found by using the cost/size exponents and the base case data shown in Table 7. However, the direct investment for the FGD process is determined by actually sizing and costing each individual piece of equipment in the FGD plant. These variations in methodology are due to the in-depth research and information available on the FGD process equipment costs; whereas, the data that are available on coal-cleaning process equipment costs are more limited.

The installed cost for the area investments includes charges for material and labor for installation of equipment, piping, foundations, excavations, electrical equipment, instruments, buildings, taxes, freight, and a 7% overtime premium for construction labor.

Capital investment cost for services, utilities, and miscellaneous is estimated to be 6% of the total process capital. The service facilities include such items as maintenance shops, stores, communications, security, offices, and road and railroad facilities. The utility investment includes the necessary electrical substations; conduit; and fire and service water, inert gas, and compressed air distribution facilities. All equipment and direct construction costs associated with waste disposal are included in waste disposal costs, including pond construction costs.

**Indirect and Other Capital Investments--**

Indirect costs consist of engineering design and supervision, architect and engineering contractor cost, construction expense, contractor fees, and

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(PREVIOUSLY CIN. EPA FORM 287)

contingency. The contingency is calculated as a percentage of the sum of the direct and indirect investments less mobile equipment cost. The allowance for startup and modifications is applied as a percentage of the total fixed investment. The startup and modification costs for the waste disposal area are assumed to be negligible. The percentage factors are shown in Table 8.

## TABLE 7. VARIABLES USED IN DETERMINING COAL-CLEANING AREA INVESTMENT

| Area | Base case[a]<br>Flow rate, ton/hr | <br>Installed cost, 1982 k$ | Cost/size exponents |
|---|---|---|---|
| Raw coal storage | 428.00 | 3,600 | 0.50 |
| Raw coal sizing | 836.00 | 1,880 | 0.74 |
| Coarse coal cleaning | | | |
| Clean coal handling | 262.00 | 1,695 | 0.53 |
| Refuse handling | 47.00 | 136 | 0.64 |
| Intermediate coal cleaning | | | |
| Total coal handling | 458.00 | 898 | 0.56 |
| Clean coal handling | 384.00 | 1,359 | 0.64 |
| Refuse handling | 75.00 | 342 | 0.64 |
| Fine coal cleaning | | | |
| Total coal handling | 69.00 | 575 | 0.72 |
| Clean coal handling | 58.00 | 921 | 0.54 |
| Refuse handling | 11.00 | 1,619 | 0.43 |
| Refuse disposal | 143.00 | 3,534 | 0.71 |
| Clean coal storage | 381.00 | 3,402 | 0.50 |

a. Base case data taken from Reference 1.

The cost of borrowed funds (interest) during construction is 15.6% of the total fixed investment. The interest factor is equivalent to 10% weighted cost of capital, assuming 25% of the construction expenditures in the first year, 50% the second year, and 25% the third year of the project construction schedule. Expenditures are assumed to be uniform over each year. Startup costs are assumed to occur so late in the project schedule that there are no charges for the use of money to pay startup costs.

All land associated with the process and waste disposal area is charged to the process. The cost of land is 5,000 $/acre. Working capital is the sum of 1 month of raw material costs, 1.5 months of conversion costs, and 1.5 months of plant and administrative overhead costs. In addition, it includes 3% of the total direct investment, excluding pond and landfill.

## TABLE 8. PERCENTAGE FACTORS FOR PROPORTIONED INVESTMENTS

| | Mobile equipment | Process PCC | Process FGD | Pond | Landfill |
|---|---|---|---|---|---|
| | % of direct investment | | | | |
| **Indirect Investment** | | | | | |
| Engineering design and supervision | 0 | 7 | 6 | 2 | 2 |
| Architect and engineering contractor | 0 | 2 | 1 | 1 | 1 |
| Construction expense | 0 | 16 | 14 | 8 | 8 |
| Contractor fees | 0 | 5 | 4 | 5 | 5 |
| Total indirect investment | 0 | 30 | 25 | 16 | 16 |
| | % of direct and indirect investment | | | | |
| Contingency | 0 | 10 | 10 | 10 | 10 |
| | % of total fixed investment | | | | |
| **Other Investment** | | | | | |
| Allowance for startup and modifications | 0 | 8 | 8 | 0 | 0 |
| Interest during construction | 0 | 15.6 | 15.6 | 15.6 | 15.6 |

### Annual Revenue Requirements

Annual revenue requirements are projected to 1984 and are based on 5,500 hr/yr of operation at full capacity. Annual revenue requirements consist of various direct and indirect operating and maintenance costs, and capital charges. Both first-year and levelized annual revenue requirements are determined. Levelized annual revenue requirements are based on a 10% discount factor and a 6% inflation rate over the 30-year life of the plant.

Direct Cost--

Direct cost consists of raw materials and conversion costs, including labor and utilities. The projected 1984 unit costs for raw materials, labor, and utilities are shown in Table 9. Maintenance costs are estimated as a percentage of the direct investment and are varied according to process complexity and size. The percentages used are 6% for the coal-cleaning process, 7% for the FGD process, and 3% for the disposal pond. Other elements of the direct costs for the coal-cleaning process are determined from the various cost/size exponents and base case data as shown in Table 10, but those for the FGD process are determined directly from the process equipment requirements or the material balance.

### TABLE 9. PROJECTED 1984 UNIT COSTS FOR RAW MATERIALS, LABOR, AND UTILITIES

| | 1984 $/unit |
|---|---|
| Raw materials | |
| Limestone | 8.50/ton |
| Raw coal | 20.81/ton |
| Cleaned coal | 55.00/ton |
| Magnetite | 107.35/ton |
| Labor | |
| Operating labor | 15.00/man-hr |
| Analyses | 21.00/man-hr |
| Mobile equipment | 21.00/man-hr |
| Utilities | |
| Process water | 0.14/kgal |
| Electricity | 0.037/kWh |
| Steam | 2.50/klb |
| Diesel fuel | 1.60/gal |

### TABLE 10. VARIABLES USED IN DETERMINING COAL-CLEANING PROCESS DIRECT COSTS

| | Base case[a] | | |
|---|---|---|---|
| | Capacity, ton/hr | Annual quantity | Exponent |
| Operating labor and supervision | 862 | 24 men/shift | 0.20 |
| Process water[b] | | | |
| Electricity | 862 | 15,110,000 kWh | 1.00 |
| Diesel fuel | 143 | 145,000 gal | 0.70 |
| Process material, magnetite | 862 | 2,760 ton | 1.00 |
| Analysis | 862 | 4,000 man-hr | 0.10 |

a. Base case data from Reference 1.

b. Process water is calculated from the material balance.

**Indirect Costs--**

Capital charges are those costs incurred for recovering the capital investment for construction of the facility and must be recovered during its life. The annual capital charges are based on the total capital investment and consist of charges for the capital recovery factor, interim replacement, insurance, property taxes, State and Federal income taxes, and credits for investment and accelerated depreciation. The levelized annual capital charges, as shown in Table 11, are 14.7% of the total capital investment.

TABLE 11. LEVELIZED ANNUAL CAPITAL CHARGES FOR REGULATED UTILITY FINANCING

| | Capital charge, % |
|---|---|
| Capital recovery factor | 10.61 |
| Interim replacements | 0.56 |
| Insurance and property taxes | 2.50 |
| Income tax | 4.31 |
| Investment credit | (1.92) |
| Accelerated depreciation | (1.36) |
| Total | 14.70 |

Plant and administrative overhead is 60% of the conversion costs excluding utilities. The plant and administrative overheads include a variety of plant services. Fringe benefits such as retirement, vacation, and dental and medical plans are included in the base wage rates.

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# RESULTS AND ILLUSTRATIVE EXAMPLES OF MODEL USE

Discussed in previous sections of this report is a computer model that will: (1) simulate the performance and economics of a coal-cleaning process, (2) simulate the performance and economics of two FGD processes (one cleaning flue gas from raw coal combustion and the other cleaning flue gas from cleaned coal combustion), and (3) determine selected economic benefits and penalties in the overall power plant design and operation attributable to coal cleaning. A users manual which gives descriptions of the input data required by the model and the procedures needed to execute it is also being developed (27).

The data obtained from this model are expected to be useful in a variety of ways. Some of these uses are:

- To determine the most economical approach to $SO_2$ emission control using coal cleaning, FGD, and their combination under a specific set of user-defined conditions.
- To illustrate the effects of a change in a particular process variable on the performance and economics of a particular coal-cleaning, FGD, or a combined coal-cleaning - FGD process.
- To analyze the importance of the economic benefits and penalties in power plant design operation that are attributable to coal cleaning.
- To compare the process performance and economics for different coal-cleaning, FGD, and combined coal-cleaning - FGD process designs (given that the necessary input data are available).

One objective of this report is to illustrate some of the potential uses of the combined coal-cleaning - FGD computer model. To accomplish this, the model was executed over a range of conditions, as shown in Table 12. These conditions include 80 runs of the combined model utilizing the four premises coals cleaned at four different specific gravities with the flue gas emissions restricted to each of the five limits. Also included were six runs which differ from the base case either in cleaned coal topsize, power plant megawatt rating, raw coal ash content, or the distance between the cleaning and power plants. In addition, 20 runs were made with the FGD segment of the model using the four premise coals (Illinois No. 6, Pittsburgh, Upper Freeport, and Cedar Grove) and the five emission limits (1979 NSPS and 0.6, 1.2, 2.0, and 4.0 lb $SO_2$/MBtu).

## TABLE 12. CONDITIONS EVALUATED

| Case No. | Coal | Specific gravity of separation | Emission standard | Raw coal topsize, in. | Plant size, MW | Raw coal ash content, % | FGD required | Transportation distance to power plant, miles |
|---|---|---|---|---|---|---|---|---|
| 1 | ILL6 | 1.4 | 79NS | 3 | 1,000 | 29.39 | Yes | 500 |
| 2 | ILL6 | 1.4 | 0.6S | 3 | 1,000 | 29.39 | Yes | 500 |
| 3 | ILL6 | 1.4 | 1.2S | 3 | 1,000 | 29.39 | Yes | 500 |
| 4 | ILL6 | 1.4 | 2.0S | 3 | 1,000 | 29.39 | Yes | 500 |
| 5 | ILL6 | 1.4 | 4.0S | 3 | 1,000 | 29.39 | No | 500 |
| 6 | ILL6 | 1.5 | 79NS | 3 | 1,000 | 29.39 | Yes | 500 |
| 7 | ILL6 | 1.5 | 0.6S | 3 | 1,000 | 29.39 | Yes | 500 |
| 8 | ILL6 | 1.5 | 1.2S | 3 | 1,000 | 29.39 | Yes | 500 |
| 9 | ILL6 | 1.5 | 2.0S | 3 | 1,000 | 29.39 | Yes | 500 |
| 10 | ILL6 | 1.5 | 4.0S | 3 | 1,000 | 29.39 | No | 500 |
| 11 | ILL6 | 1.6 | 79NS | 3 | 1,000 | 29.39 | Yes | 500 |
| 12 | ILL6 | 1.6 | 0.6S | 3 | 1,000 | 29.39 | Yes | 500 |
| 13 | ILL6 | 1.6 | 1.2S | 3 | 1,000 | 29.39 | Yes | 500 |
| 14 | ILL6 | 1.6 | 2.0S | 3 | 1,000 | 29.39 | Yes | 500 |
| 15 | ILL6 | 1.6 | 4.0S | 3 | 1,000 | 29.39 | Yes | 500 |
| 16 | ILL6 | 1.8 | 79NS | 3 | 1,000 | 29.39 | Yes | 500 |
| 17 | ILL6 | 1.8 | 0.6S | 3 | 1,000 | 29.39 | Yes | 500 |
| 18 | ILL6 | 1.8 | 1.2S | 3 | 1,000 | 29.39 | Yes | 500 |
| 19 | ILL6 | 1.8 | 2.0S | 3 | 1,000 | 29.39 | Yes | 500 |
| 20 | ILL6 | 1.8 | 4.0S | 3 | 1,000 | 29.39 | Yes | 500 |
| 21 | PITT | 1.4 | 79NS | 3 | 1,000 | 13.81 | Yes | 500 |
| 22 | PITT | 1.4 | 0.6S | 3 | 1,000 | 13.81 | Yes | 500 |
| 23 | PITT | 1.4 | 1.2S | 3 | 1,000 | 13.81 | Yes | 500 |
| 24 | PITT | 1.4 | 2.0S | 3 | 1,000 | 13.81 | Yes | 500 |
| 25 | PITT | 1.4 | 4.0S | 3 | 1,000 | 13.81 | No | 500 |
| 26 | PITT | 1.5 | 79NS | 3 | 1,000 | 13.81 | Yes | 500 |
| 27 | PITT | 1.5 | 0.6S | 3 | 1,000 | 13.81 | Yes | 500 |
| 28 | PITT | 1.5 | 1.2S | 3 | 1,000 | 13.81 | Yes | 500 |
| 29 | PITT | 1.5 | 2.0S | 3 | 1,000 | 13.81 | Yes | 500 |
| 30 | PITT | 1.5 | 4.0S | 3 | 1,000 | 13.81 | No | 500 |
| 31 | PITT | 1.6 | 79NS | 3 | 1,000 | 13.81 | Yes | 500 |
| 32 | PITT | 1.6 | 0.6S | 3 | 1,000 | 13.81 | Yes | 500 |
| 33 | PITT | 1.6 | 1.2S | 3 | 1,000 | 13.81 | Yes | 500 |
| 34 | PITT | 1.6 | 2.0S | 3 | 1,000 | 13.81 | Yes | 500 |
| 35 | PITT | 1.6 | 4.0S | 3 | 1,000 | 13.81 | Yes | 500 |
| 36 | PITT | 1.8 | 79NS | 3 | 1,000 | 13.81 | Yes | 500 |
| 37 | PITT | 1.8 | 0.6S | 3 | 1,000 | 13.81 | Yes | 500 |
| 38 | PITT | 1.8 | 1.2S | 3 | 1,000 | 13.81 | Yes | 500 |
| 39 | PITT | 1.8 | 2.0S | 3 | 1,000 | 13.81 | Yes | 500 |
| 40 | PITT | 1.8 | 4.0S | 3 | 1,000 | 13.81 | Yes | 500 |

(Continued)

TABLE 12. (Continued)

| Case No. | Coal | Specific gravity of separation | Emission standard | Raw coal topsize, in. | Plant size, MW | Raw coal ash content, % | FGD required | Transportation distance to power plant, miles |
|---|---|---|---|---|---|---|---|---|
| 41 | UPPER | 1.4 | 79NS | 3 | 1,000 | 16.80 | Yes | 500 |
| 42 | UPPER | 1.4 | 0.6S | 3 | 1,000 | 16.80 | Yes | 500 |
| 43 | UPPER | 1.4 | 1.2S | 3 | 1,000 | 16.80 | Yes | 500 |
| 44 | UPPER | 1.4 | 2.0S | 3 | 1,000 | 16.80 | No | 500 |
| 45 | UPPER | 1.4 | 4.0S | 3 | 1,000 | 16.80 | No | 500 |
| 46 | UPPER | 1.5 | 79NS | 3 | 1,000 | 16.80 | Yes | 500 |
| 47 | UPPER | 1.5 | 0.6S | 3 | 1,000 | 16.80 | Yes | 500 |
| 48 | UPPER | 1.5 | 1.2S | 3 | 1,000 | 16.80 | Yes | 500 |
| 49 | UPPER | 1.5 | 2.0S | 3 | 1,000 | 16.80 | No | 500 |
| 50 | UPPER | 1.5 | 4.0S | 3 | 1,000 | 16.80 | No | 500 |
| 51 | UPPER | 1.6 | 79NS | 3 | 1,000 | 16.80 | Yes | 500 |
| 52 | UPPER | 1.6 | 0.6S | 3 | 1,000 | 16.80 | Yes | 500 |
| 53 | UPPER | 1.6 | 1.2S | 3 | 1,000 | 16.80 | Yes | 500 |
| 54 | UPPER | 1.6 | 2.0S | 3 | 1,000 | 16.80 | No | 500 |
| 55 | UPPER | 1.6 | 4.0S | 3 | 1,000 | 16.80 | No | 500 |
| 56 | UPPER | 1.8 | 79NS | 3 | 1,000 | 16.80 | Yes | 500 |
| 57 | UPPER | 1.8 | 0.6S | 3 | 1,000 | 16.80 | Yes | 500 |
| 58 | UPPER | 1.8 | 1.2S | 3 | 1,000 | 16.80 | Yes | 500 |
| 59 | UPPER | 1.8 | 2.0S | 3 | 1,000 | 16.80 | Yes | 500 |
| 60 | UPPER | 1.8 | 4.0S | 3 | 1,000 | 16.80 | No | 500 |
| 61 | CEDAR | 1.4 | 79NS | 3 | 1,000 | 16.04 | Yes | 500 |
| 62 | CEDAR | 1.4 | 0.6S | 3 | 1,000 | 16.04 | Yes | 500 |
| 63 | CEDAR | 1.4 | 1.2S | 3 | 1,000 | 16.04 | No | 500 |
| 64 | CEDAR | 1.4 | 2.0S | 3 | 1,000 | 16.04 | No | 500 |
| 65 | CEDAR | 1.4 | 4.0S | 3 | 1,000 | 16.04 | No | 500 |
| 66 | CEDAR | 1.5 | 79NS | 3 | 1,000 | 16.04 | Yes | 500 |
| 67 | CEDAR | 1.5 | 0.6S | 3 | 1,000 | 16.04 | Yes | 500 |
| 68 | CEDAR | 1.5 | 1.2S | 3 | 1,000 | 16.04 | No | 500 |
| 69 | CEDAR | 1.5 | 2.0S | 3 | 1,000 | 16.04 | No | 500 |
| 70 | CEDAR | 1.5 | 4.0S | 3 | 1,000 | 16.04 | No | 500 |
| 71 | CEDAR | 1.6 | 79NS | 3 | 1,000 | 16.04 | Yes | 500 |
| 72 | CEDAR | 1.6 | 0.6S | 3 | 1,000 | 16.04 | Yes | 500 |
| 73 | CEDAR | 1.6 | 1.2S | 3 | 1,000 | 16.04 | No | 500 |
| 74 | CEDAR | 1.6 | 2.0S | 3 | 1,000 | 16.04 | No | 500 |
| 75 | CEDAR | 1.6 | 4.0S | 3 | 1,000 | 16.04 | No | 500 |
| 76 | CEDAR | 1.8 | 79NS | 3 | 1,000 | 16.04 | Yes | 500 |
| 77 | CEDAR | 1.8 | 0.6S | 3 | 1,000 | 16.04 | Yes | 500 |
| 78 | CEDAR | 1.8 | 1.2S | 3 | 1,000 | 16.04 | No | 500 |
| 79 | CEDAR | 1.8 | 2.0S | 3 | 1,000 | 16.04 | No | 500 |
| 80 | CEDAR | 1.8 | 4.0S | 3 | 1,000 | 16.04 | No | 500 |

(Continued)

TABLE 12. (Continued)

| Case No. | Coal | Specific gravity of separation | Emission standard | Raw coal topsize, in. | Plant size, MW | Raw coal ash content, % | FGD required | Transportation distance to power plant, miles |
|---|---|---|---|---|---|---|---|---|
| Case Variations | | | | | | | | |
| 81 | PITT | 1.6 | 1.2S | 1.5 | 1,000 | 13.81 | Yes | 500 |
| 82 | PITT | 1.6 | 1.2S | 3 | 1,500 | 13.81 | Yes | 500 |
| 83 | PITT | 1.6 | 1.2S | 3 | 2,000 | 13.81 | Yes | 500 |
| 84 | PITT | 1.6 | 1.2S | 3 | 1,000 | 13.81 | Yes | 250 |
| 85 | PITT | 1.6 | 1.2S | 3 | 1,000 | 13.81 | Yes | 750 |
| 86 | PITT | 1.6 | 1.2S | 3 | 1,000 | 13.81 | Yes | 500 |

79NS - 1979 NSPS
S - lb $SO_2$/MBtu
ILL6 = Illinois No. 6 seam
PITT = Pittsburgh seam
UPPER = Upper Freeport seam
CEDAR = Cedar Grove seam

The printouts from these runs consist of approximately 1,600 pages of computer output. For this reason, the results of these example runs are presented in two abbreviated forms. Figure A-7, in the appendix, contains a sample printout with an example of every type of page produced by the base case simulation, and Tables A-8 and A-9 contain summary data of selected results from all of the runs, except the case variations. In the discussions which follow, selected data from these tables are used to illustrate some possible uses of the model.

For the application of coal cleaning to $SO_2$ emission control, the important criteria are the reduction in the sulfur emission parameter (lb $SO_2$/MBtu) and the cost of coal cleaning. In a coal-cleaning plant of a given configuration, the specific gravity of separation is the operating condition usually measured and controlled to regulate the properties of the cleaned coal, and thus the sulfur emission parameter reduction and cost of the process. For this reason, it is the primary input variable used in the model to define the cleaning process operating conditions. Among the important performance criteria determined by the specific gravity of separation are the yield, sulfur reduction efficiency, and the Btu recovery. The yield is the weight of the cleaned coal produced by the plant divided by the weight of raw coal feed. The sulfur reduction efficiency is determined by the coal washability and the amount and size distribution of coal minerals, especially pyrite. The Btu recovery is the percentage of the Btu content of the raw coal that remains when the coal is cleaned. It is a measure of both the cleaned coal properties and the economics of the process since the Btu loss in the refuse is an important economic factor in coal cleaning. Btu recovery is used in these illustrative examples as a measure of the coal-cleaning plant operating performance and the economics of the process.

## OPERATING PERFORMANCE

The performance of a coal-cleaning plant can be measured by the yield and the Btu recovery. These closely and inversely related elements are determined by the coal washability, the cleaning plant design and equipment efficiencies, and the specific gravity of separation. The performance of an FGD system is usually defined by the $SO_2$ removal efficiency, which is determined by a variety of design and operating conditions. When a coal-cleaning plant is combined with an FGD system to attain a particular emission control objective, all of the many factors determining the performance of both must be considered to define the most practical and economical combination of performances. This variety of factors tends to make any analysis of the performance data somewhat complicated. In these illustrative examples, it has been simplified by limiting the analysis to one coal-cleaning process design, thus using a single set of washing equipment efficiency curves and using an FGD process that always removes 90% of the $SO_2$ in the scrubbed flue gas, thus limiting the effect of coal-cleaning plant performance on the FGD process to those resulting from changes in the amount of bypassed flue gas or boiler efficiency.

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## Coal Cleaning Performance

In most cases, the specific gravity of separation used in the washing equipment is the most important operating condition of the coal-cleaning plant. This is under the control of the plant operator and can be used to regulate the quality and quantity of the cleaned coal. For this reason, it is the process variable that is usually altered in order to determine the correct combination of coal cleaning and FGD to yield the minimum overall cost to meet the required emission standard. This optimum specific gravity of separation varies with the washability of the coal and the type of cleaning equipment being used. Btu recovery is an important measurement of the performance of a coal-cleaning process that can be closely correlated with specific gravity of separation. Btu recovery is the percentage of the total number of Btu's in the raw coal that remain in the cleaned coal. In the illustrative examples, the specific gravity of separation was used as the input variable and the equipment efficiency inputs were held constant. This defines the cleaning plant separation conditions and the Btu recovery at each specific gravity of separation for each coal. The relationships between the specific gravity of separation and Btu recovery are illustrated in Figure 5 for the four premise coals.

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The relationships of sulfur reduction and Btu recovery to the specific gravity of separation are tabulated in Table 13 for the four premise coals. From analysis of this information, it is apparent that as the specific gravity of separation increases, the sulfur reduction achieved by coal cleaning decreases, but the Btu recovery increases. The amounts of pure coal and pyritic sulfur in the refuse decrease as the specific gravity increases, although the percentages of pyrite and ash do so at a much lower rate than the percentage of pure coal. This results in a clean coal product with a higher Btu recovery but also higher in pyrite content due to the decreased amount in the refuse. This is shown graphically in Figure 6, which illustrates the relationship between the actual $SO_2$ concentration in the flue gas (taking into account the assumed removal of 8% of the sulfur in the coal with the ash) and the Btu recovery. Figure 6 also illustrates the emission limits that can be achieved simply by using coal cleaning on the four premise coals. Depending on the Btu recovery (as determined by corresponding operating specific gravity), coal cleaning alone can meet some of the less stringent emission limits, thereby making additional pollution control unnecessary. However, for most of the more stringent limits, some additional control is necessary.

An important point to consider in evaluating the performance of a coal-cleaning process is the variability in these measures of performance among different coals. The washabilities of different coals vary considerably even for coals having approximately the same sulfur content. Since the cleaning plant performance is highly dependent on the coal washability, it also varies accordingly.

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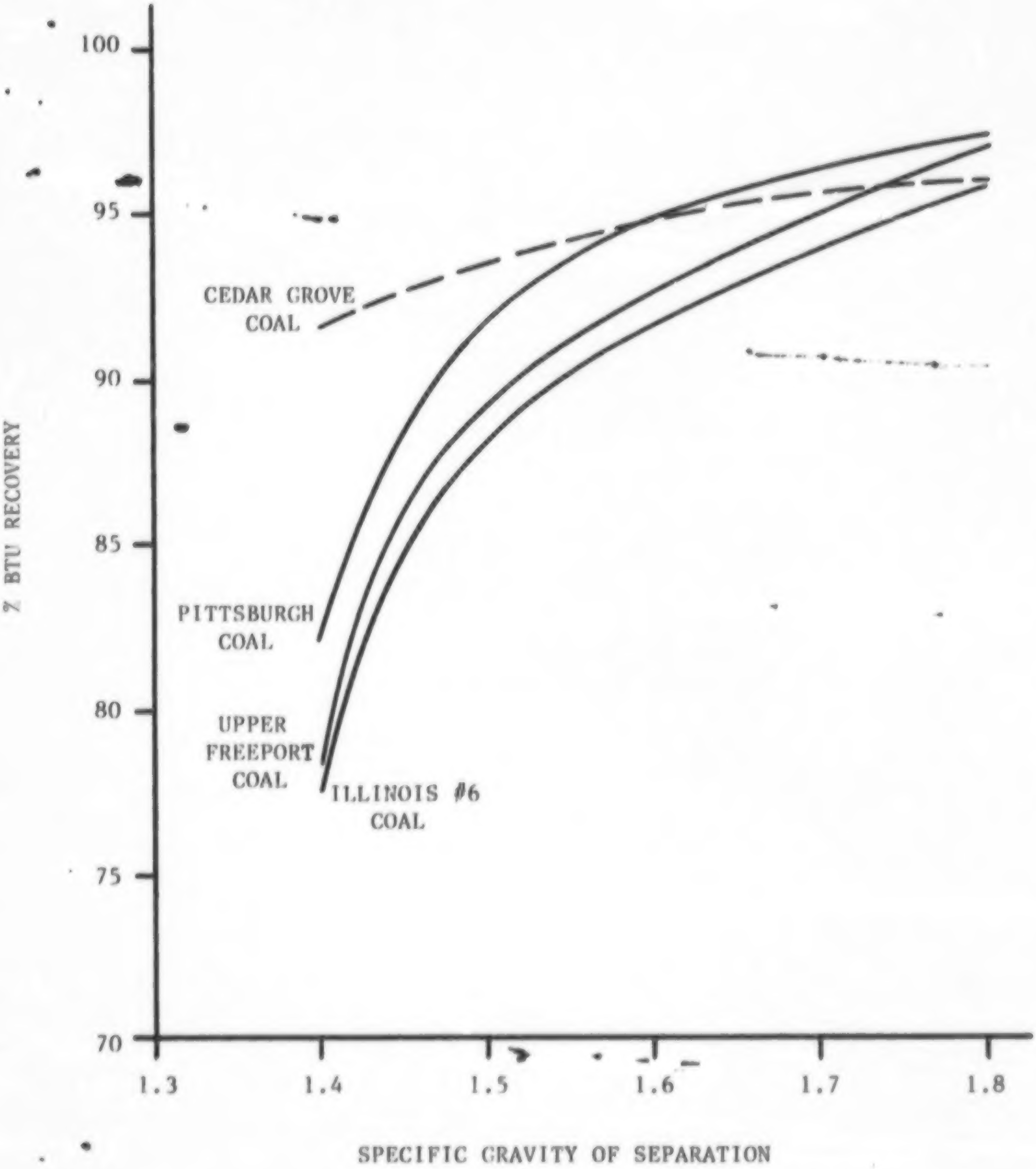

Figure 5. The effect of specific gravity of separation on Btu recovery.

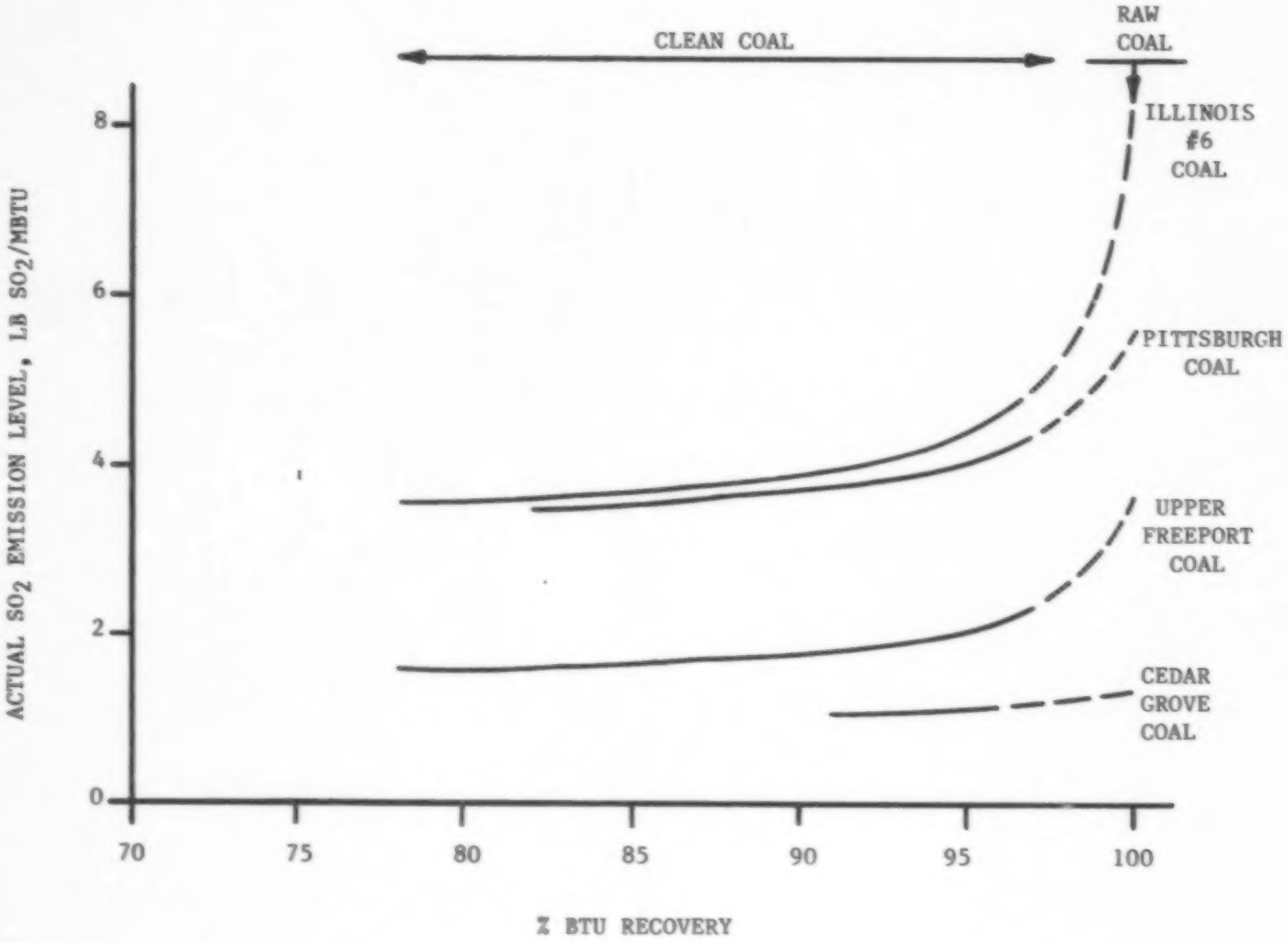

Figure 6. Effect of Btu recovery on the actual $SO_2$ emission levels.

## TABLE 13. SULFUR REDUCTION AND BTU RECOVERY BY COAL CLEANING

| | Raw coal | Coal-cleaning operating specific gravity | | | |
|---|---|---|---|---|---|
| | | 1.4 | 1.5 | 1.6 | 1.8 |
| **Illinois No. 6 Coal** | | | | | |
| Yield, % | - | 56 | 65 | 68 | 73 |
| lb $SO_2$/MBtu[a] | 8.97 | 3.86 | 4.18 | 4.38 | 5.08 |
| Sulfur reduction, % | - | 57 | 53 | 51 | 43 |
| Btu recovery, % | - | 78 | 88 | 92 | 96 |
| **Pittsburgh Coal** | | | | | |
| Yield, % | - | 73 | 83 | 86 | 91 |
| lb $SO_2$/MBtu[a] | 6.05 | 3.79 | 4.18 | 4.37 | 4.68 |
| Sulfur reduction, % | - | 37 | 31 | 28 | 23 |
| Btu recovery, % | - | 82 | 92 | 95 | 97 |
| **Upper Freeport Coal** | | | | | |
| Yield, % | - | 67 | 78 | 82 | 88 |
| lb $SO_2$/MBtu[a] | 3.97 | 1.76 | 1.93 | 2.03 | 2.35 |
| Sulfur reduction, % | - | 56 | 51 | 49 | 41 |
| Btu recovery, % | - | 78 | 89 | 93 | 97 |
| **Cedar Grove Coal** | | | | | |
| Yield, % | - | 78 | 80 | 81 | 83 |
| lb $SO_2$/MBtu[a] | 1.45 | 1.17 | 1.20 | 1.23 | 1.25 |
| Sulfur reduction, % | - | 19 | 17 | 15 | 14 |
| Btu recovery, % | - | 91 | 93 | 95 | 96 |

a. Assuming 100% conversion of sulfur as $SO_2$.

### FGD Performance

The FGD system design used in these illustrative examples is assumed to remove 90% of the $SO_2$ in the flue gas, although any desired value can be used in the model. If the requirement for $SO_2$ removal is less than 90%, some flue gas is bypassed which reduces the steam requirements for reheating because the bypassed flue gas is combined with the scrubbed flue gas to provide some of the reheat. This design is more economical than full scrubbing at lower $SO_2$ removal requirements primarily because the reheat energy requirements are reduced. Above approximately 30%, bypass no reheating is required. The capital investment for reheating is relatively low but reheating steam costs constitute about one-fifth of the annual revenue requirements conversion costs. The percentage of the flue gas bypassed varies with the emission limit and the heating value and sulfur content in the raw coal, as shown in Figure 7. As the permissible emission limit increases, the quantity of flue gas bypassed rapidly increases for each coal. For example, the percentage of flue gas bypassed reaches 100% (i.e., no FGD is required) at a 1.35 lb $SO_2$/MBtu emission limit for the Cedar Grove coal with no coal cleaning.

### Combined Coal Cleaning and FGD

When coal cleaning is combined with FGD to achieve a particular emission limitation with a particular coal, the performance of the coal-cleaning plant determines the performance requirement of the FGD system. In these illustrative examples, the performance of the coal-cleaning plant is defined in terms of sulfur reduction and Btu recovery for four coals and four specific gravities of separation. Each specific gravity with resulting Btu recovery produces a new cleaned coal with a particular heating value and sulfur content, thus requiring a different FGD performance to attain a given emission limit. For the FGD system used, the quantity of bypassed flue gas is used to define FGD performance since this has the major effect on FGD costs. The effect of Btu recovery on the percent bypassed is illustrated in Figure 8 for the premise coals at the 1.2 lb $SO_2$/MBtu emission limit.

## ECONOMICS

One use of the combined model is to find the most economical combination of coal cleaning and FGD to meet a specified emission limit. The operating conditions for this optimum combination are not constant for every case because they vary with the different process characteristics such as cleaning equipment efficiencies, the raw coal composition, and the coal washability. Usually this necessitates the use of trial and error to determine the optimum operating conditions for each case. The model produces values for the capital investment, first-year annual revenue requirements, and levelized annual revenue requirements for either (1) a coal-cleaning process; (2) a combined coal-cleaning - FGD process; or (3) an FGD process, depending on the input specifications. A summary of the results of model runs at the conditions listed in Table 12 is shown in Tables A-2 and A-3 in the appendix. For the results from the combined coal-cleaning - FGD runs, the net cost is composed of the cost for the coal-cleaning process, reduction in cost of the FGD process, and other costs (or cost reduction) generated by the benefits and penalties program. Specific results are discussed below.

### Capital Investment

The capital investments for the Illinois No. 6 and Pittsburgh coals at the five emission limits and the four specific gravities of separation

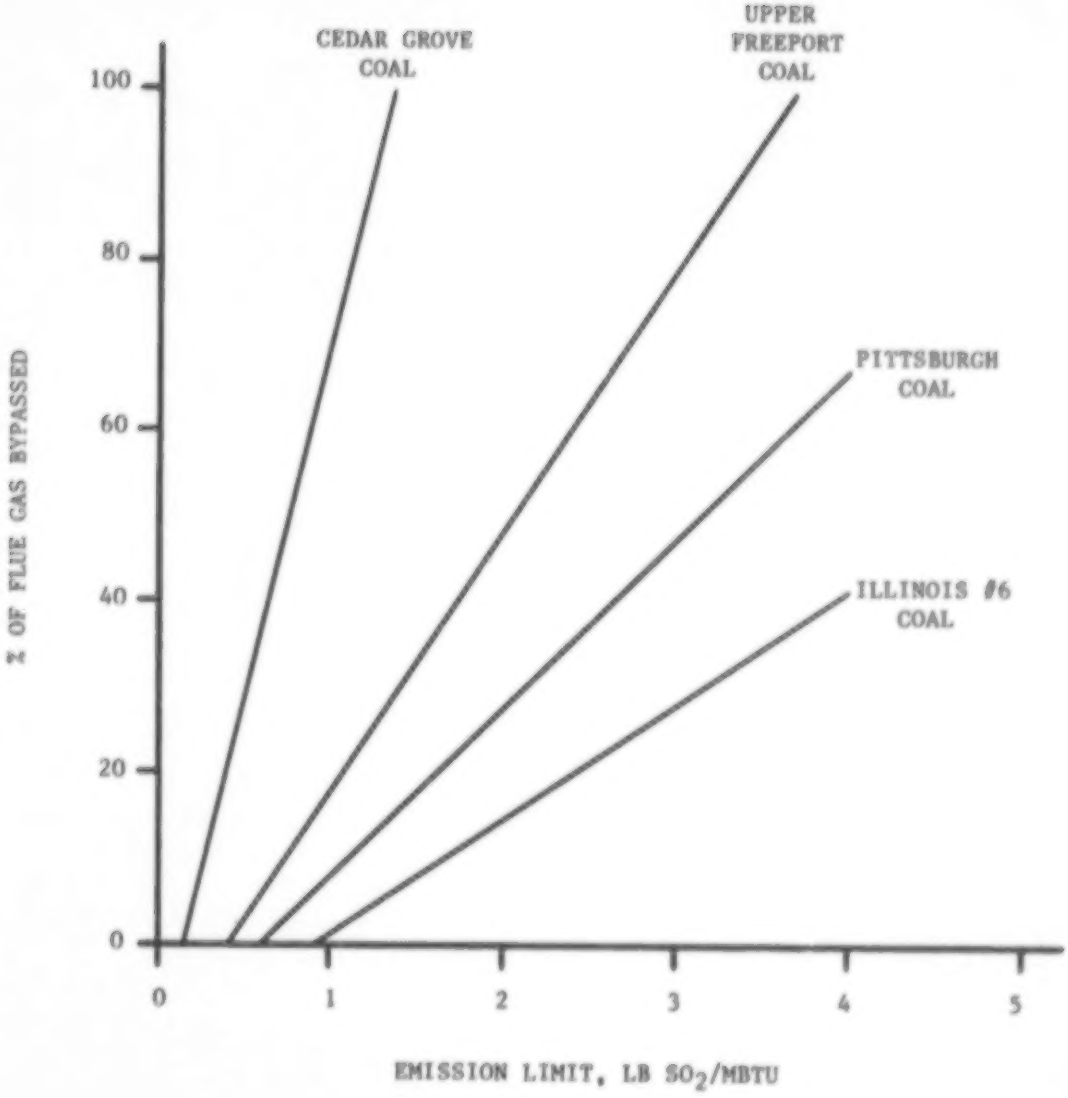

Figure 7. Effect of the emission limit on the flue gas bypassed when burning the four premise coals (FGD alone with no coal cleaning).

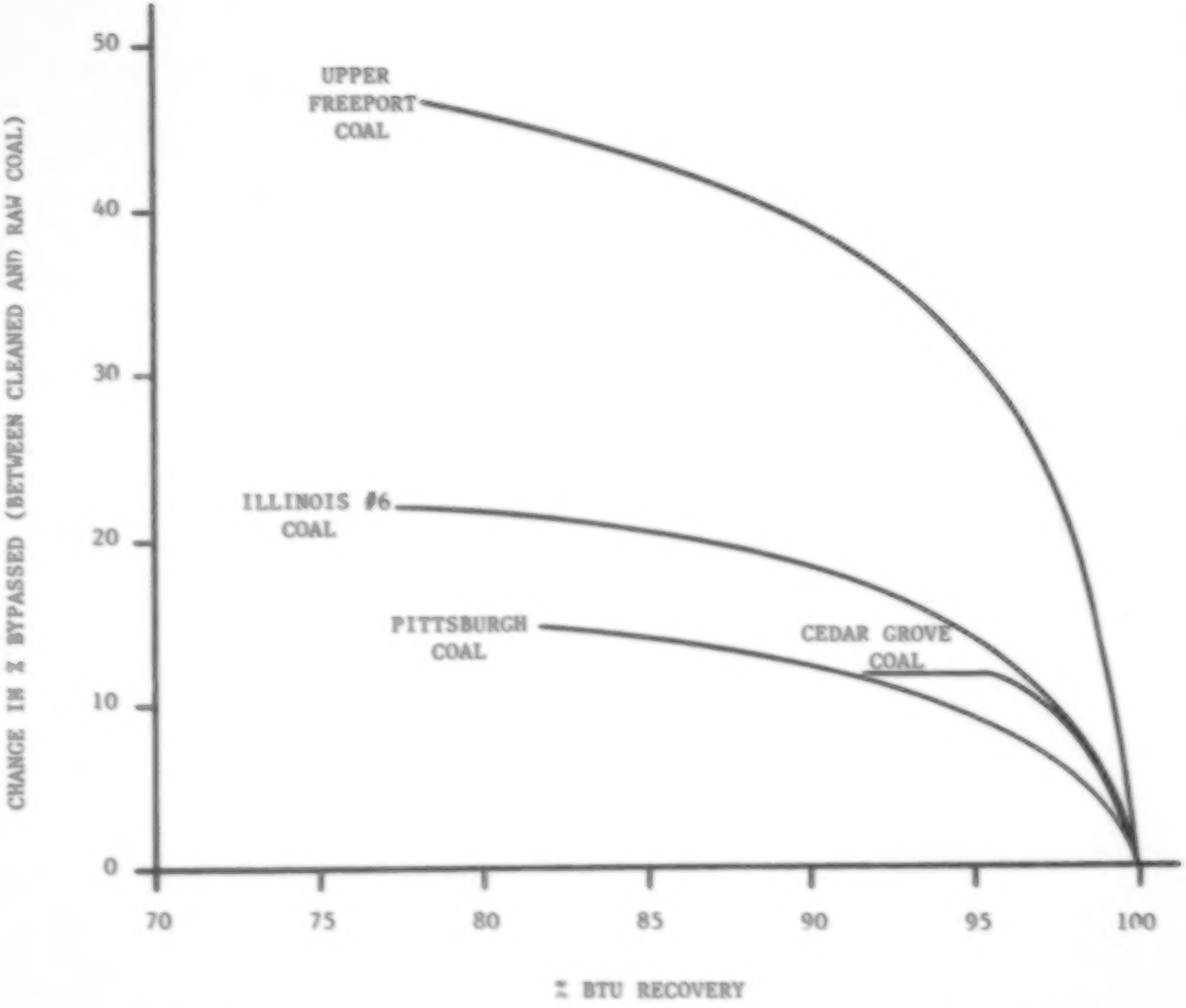

Figure 8. Effect of Btu recovery on the flue gas bypassed at the 1.2 lb $SO_2$/MBtu emission limit.

(expressed as Btu recovery) are shown in Figures 9 and 10. For most cases, the value for the net capital investment (coal-cleaning costs less all benefits including FGD) are negative numbers. This indicates that the capital investment benefits, less penalties, which can be attributed to the use of cleaned coal are greater than the total capital investment required to build the cleaning plant. In these cases, the use of coal cleaning combined with FGD to meet the specified emission limit would be less expensive, from the standpoint of capital investment, than FGD alone.

This is not always the case as can be seen in Figure 10. These curves for the Pittsburgh coal indicate that in some cases the conditions are such that the net capital investment for the combined coal-cleaning - FGD process has a higher capital investment than FGD alone. In these cases, it would be more advisable in terms of capital investment to use only FGD. For the Pittsburgh coal, this is usually the case at the higher Btu recoveries and more stringent emission limits. The reason for this is the reduced FGD capital investment benefit because of the inherently higher sulfur content of cleaned coal that accompanies higher Btu recoveries.

Some of the curves in Figures 9 and 10 have minimum points. These points on the curves are the conditions at which a combined coal-cleaning - FGD process would be designed to minimize the total capital investment requirement of the system. Such an optimum point exists for most cases but it cannot always be seen in these figures because for some of the conditions it occurs at Btu recoveries beyond the range of the runs made for this report. To more fully illustrate the significance of this point, Figure 11 shows the effect of Btu recovery on the components of the net capital investment for the Pittsburgh coal and the 1.20 lb $SO_2$/MBtu emission limit. For this set of conditions, the net cost curve is at a minimum point at approximately 75% Btu recovery which corresponds roughly to 1.37 specific gravity of separation in the coal-cleaning process using the Pittsburgh coal.

It was mentioned previously that the reason for the increased net cost of a coal-cleaning - FGD process at the higher Btu recoveries is the reduction in the FGD capital investment benefit. This was attributed to the higher sulfur content that accompanies higher Btu recoveries. This is supported in Figure 11 by the shape of the curve corresponding to the change in the FGD capital investment resulting from the use of cleaned coal, which changes more dramatically than the other components of net cost. Again, this is due to the increased FGD requirement necessary because of the higher sulfur content of the cleaned coal produced at higher Btu recoveries.

## Annual Revenue Requirements

The levelized annual revenue requirements for the Illinois No. 6 and Pittsburgh coals at the five emission limits and four specific gravities of separation (expressed as Btu recovery) are shown in Figures 12 and 13. It should be noted that because of the large difference in values, the scales are not the same on these figures.

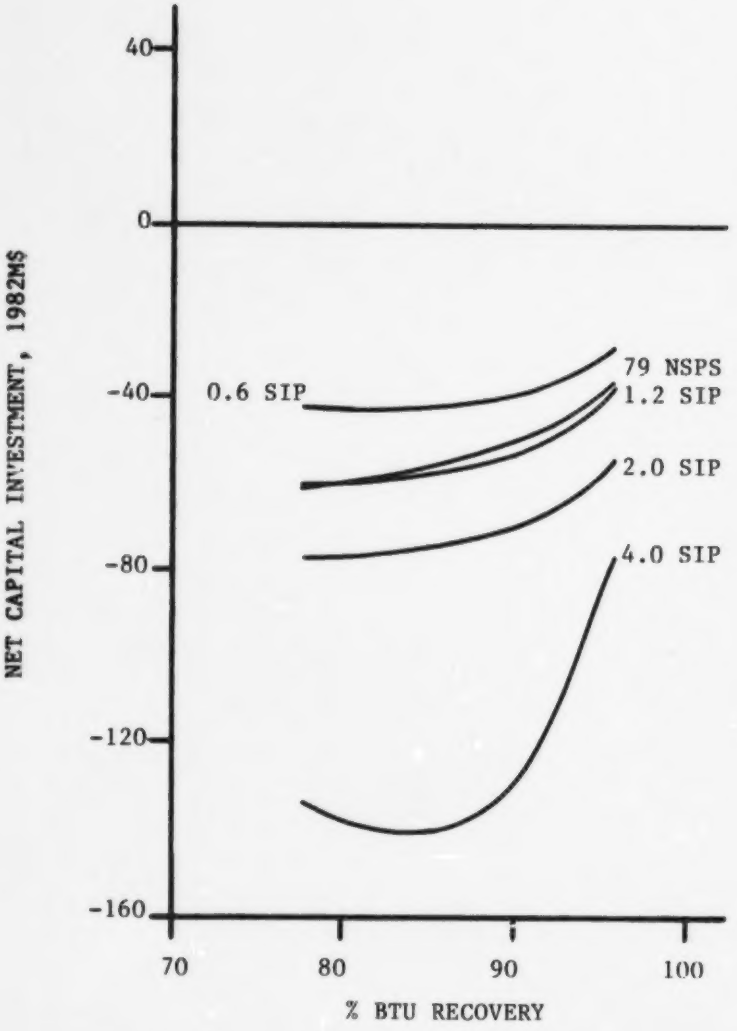

Figure 9. Btu recovery versus net capital investment for coal cleaning, Illinois No. 6 coal.

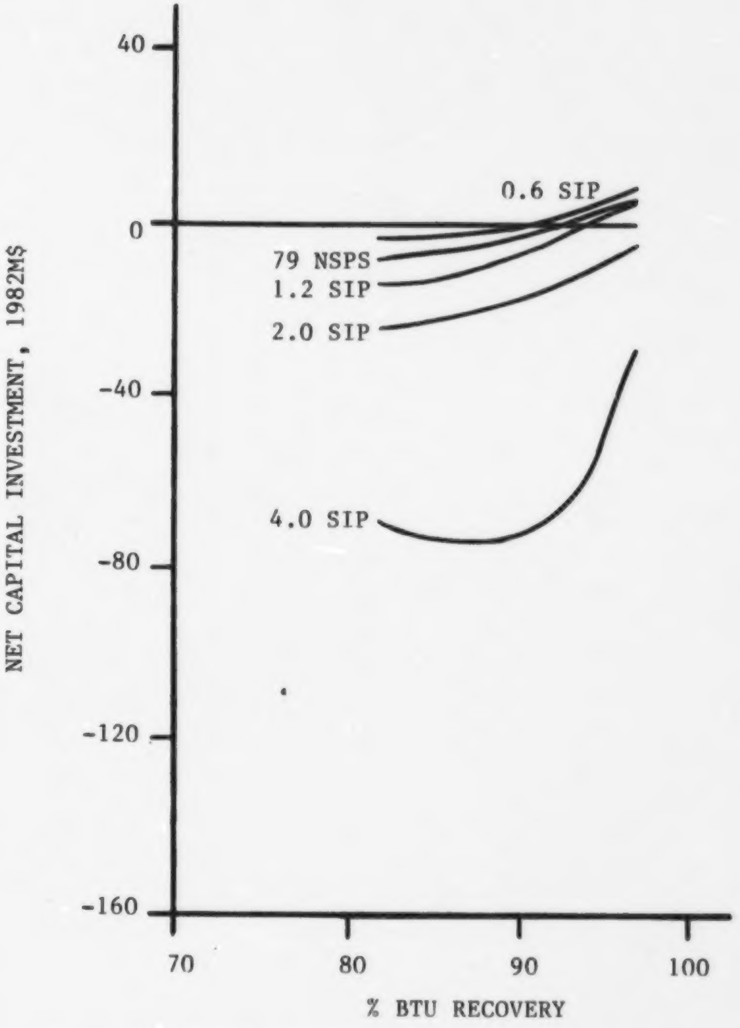

Figure 10. Btu recovery versus net capital investment for coal cleaning, Pittsburgh coal.

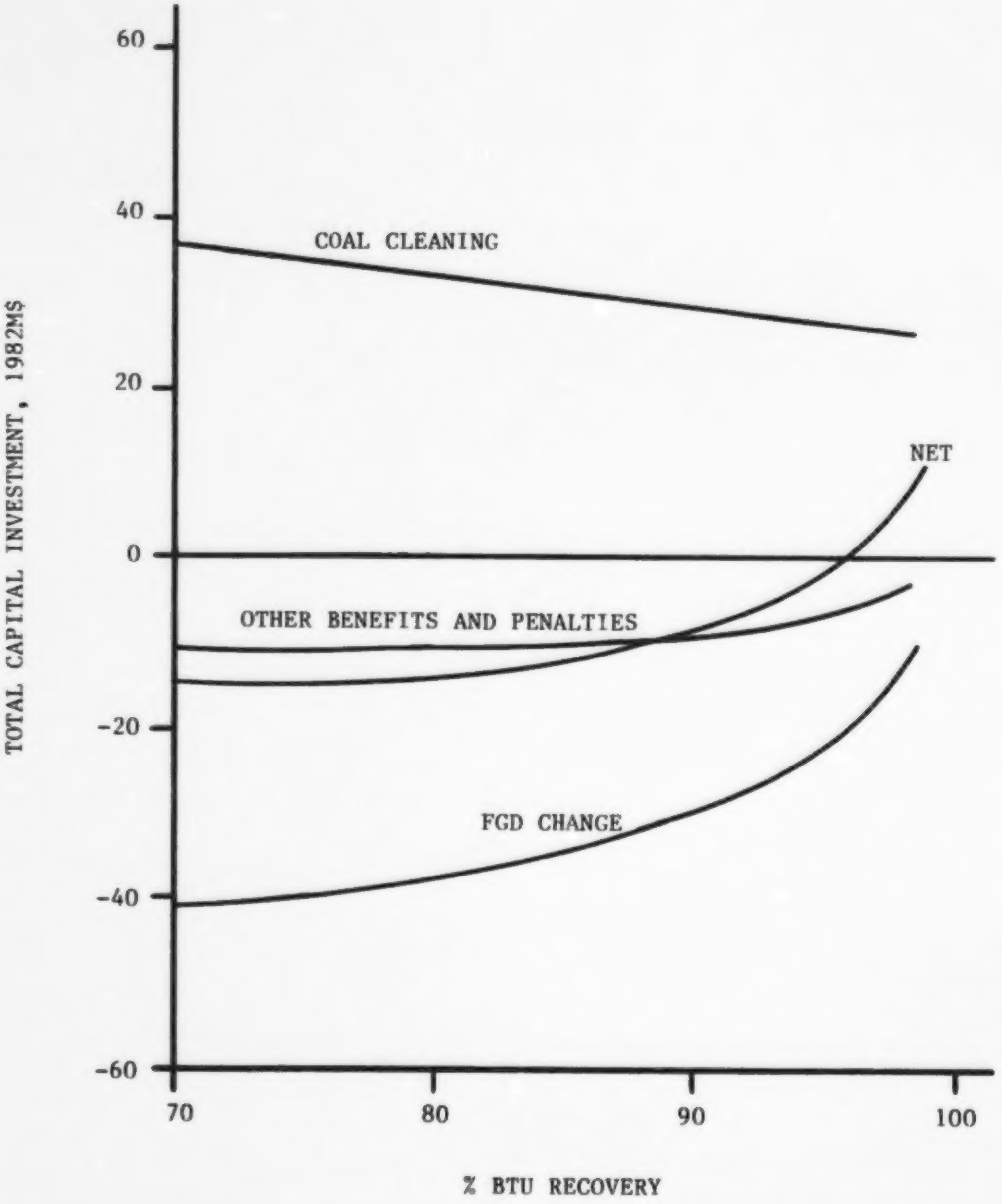

Figure 11. Effect of Btu recovery on the net total capital investment for a coal-cleaning process, including all benefits and penalties, Pittsburgh coal at 1.20 emission limit.

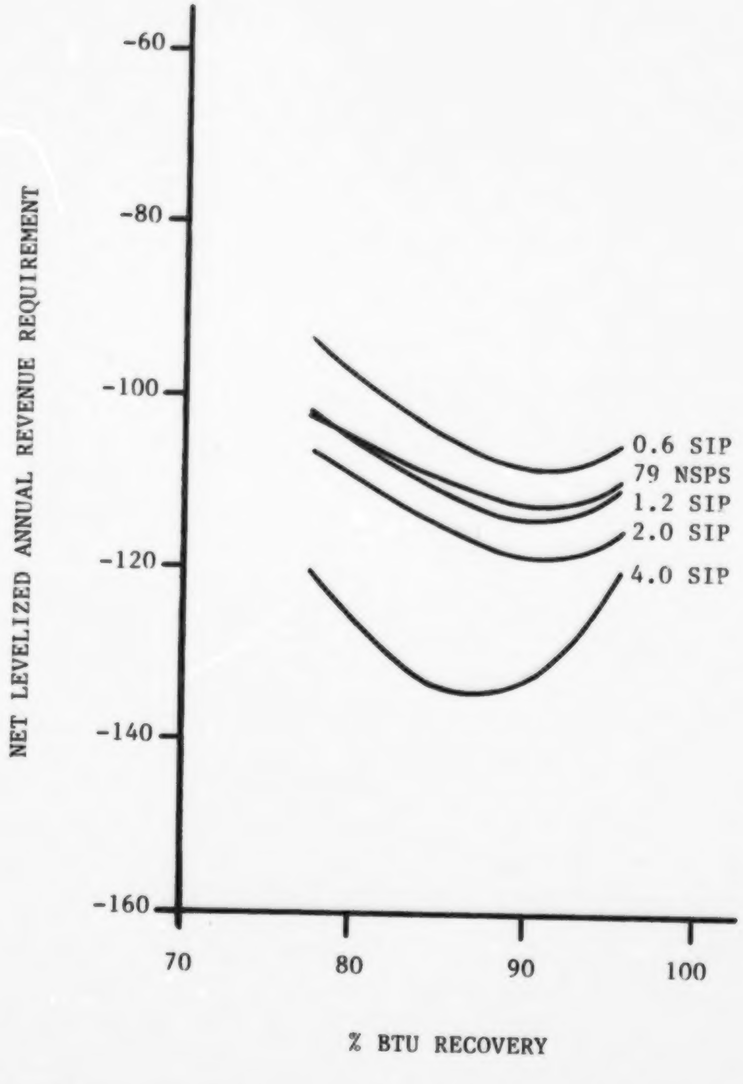

Figure 12. Btu recovery versus net levelized annual revenue requirements, Illinois No. 6 coal.

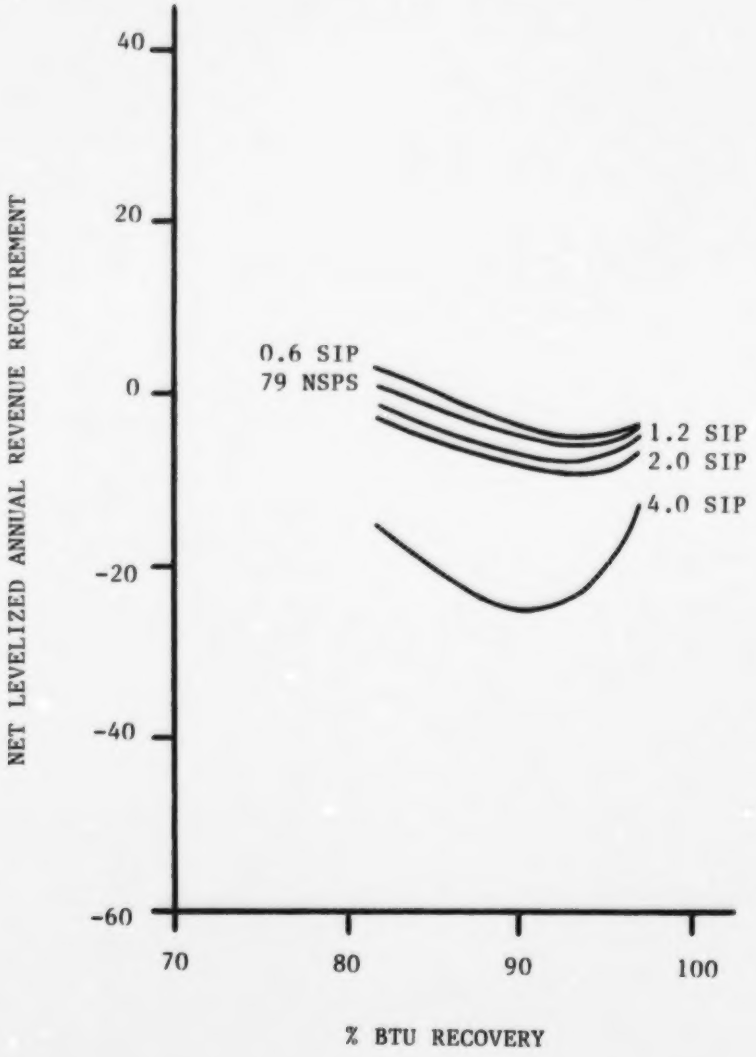

Figure 13. Btu recovery versus net levelized annual revenue requirements, Pittsburgh coal.

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From these figures, it can be seen that in contrast to the capital investment, which is relatively insensitive to Btu recovery, the annual revenue requirements change rapidly as the Btu recovery changes. This is generally due to the greater number of factors of power plant annual revenue requirements which are affected by coal cleaning and considered in the benefits/penalties program. In particular, there are 10 areas of revenue requirements that are affected, but only 4 areas of capital investment. Of these 10 areas, coal lost to the refuse is the one most influenced by Btu recovery, and it is the single largest factor in the shape of the annual revenue requirements curve.

As was the case with the curves for the net total capital investment for the combined process, the curves in Figures 12 and 13 have points where the net levelized annual revenue requirements are at a minimum. The operating conditions corresponding to these optimum points are those at which the combined process should be designed and operated to achieve the lowest annual revenue requirements. Figure 14 further illustrates the composition of the net annual revenue requirements by presenting the effect of Btu recovery on the various components. At the stated conditions, the net cost curve shows a minimum point at about 93% Btu recovery which corresponds to about 1.55 specific gravity of separation.

Comparing the net cost curves in Figures 11 and 14, the net capital investment curve and the net annual revenue requirements curve differ appreciably in shape and have different minima. This difference is primarily a result of the different responses of the other benefits and penalties to changes in the separation gravity--in contrast to the FGD costs, which steadily decline as the specific gravity of separation decreases. The sum of the other benefits and penalties reaches a maximum net benefit (minimum cost) at a certain specific gravity after which reductions in the gravity of separation produce a decrease in the net benefits (increase in costs). This is particularly true of annual revenue requirements in which the rapidly increasing Btu loss, as the specific gravity decreases, produces a sharp decrease in the net benefit, and eventually results in a net penalty. In optimizing the economics of a combined coal-cleaning - FGD process for a particular combination of conditions, it is therefore necessary to establish the relative importance of capital investment and annual revenue requirements to establish optimum cleaning requirements. In particular, operating at a low specific gravity greatly increases the annual revenue requirements because of high coal loss. On the other hand, operating at a high specific gravity also increases net annual revenue requirements because of the low level of sulfur removal.

## Case Variations and Sensitivities

The economics of combined coal cleaning - FGD are affected by variables such as power plant capacity, raw coal topsize, ash content of raw coal, and transportation distance. The effects of variations in these criteria are discussed below for the Pittsburgh coal with coal cleaning at a 1.6 specific gravity using a combined process to meet the 1.2 lb $SO_2$/MBtu emission limit.

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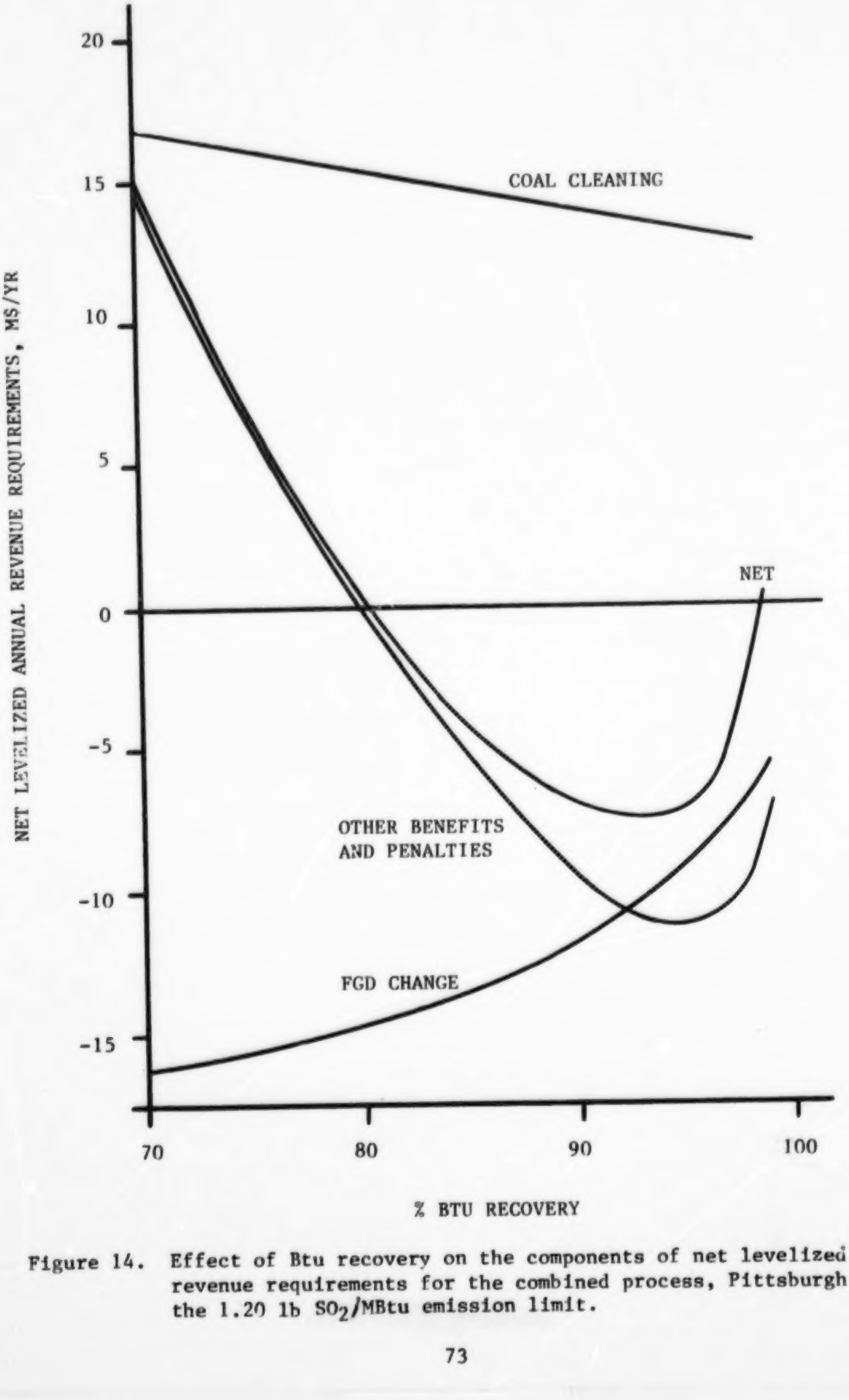

Figure 14. Effect of Btu recovery on the components of net levelized annual revenue requirements for the combined process, Pittsburgh coal at the 1.20 lb $SO_2$/MBtu emission limit.

Power Plant Capacity--

The sensitivities of the capital investment and levelized annual revenue requirements to power plant capacity are shown in Table 14. The net capital investment and annual revenue requirements are very sensitive to power plant capacity but it should be remembered that these costs are incremental and are subject to an unusually high economy of scale. For example, a 50% increase in power plant capacity will reduce both the net capital investment and the annual revenue requirements as referenced to the base case by about 100% and 173%, respectively.

TABLE 14. NET TOTAL CAPITAL INVESTMENT AND LEVELIZED ANNUAL REVENUE REQUIREMENTS FOR VARIOUS POWER PLANT SIZES

| Power plant size, MW | Net total capital investment, 1982$ |  | Net levelized annual revenue requirements, 1984$ |  |
|---|---|---|---|---|
|  | M$ | % change | M$ | % change |
| 1,000 (base) | -2.7 | - | -6.3 | - |
| 1,500 | -5.6 | +107.4 | -18.3 | +190.5 |
| 2,000 | -9.3 | +244.4 | -47.1 | +647.6 |

Basis: Pittsburgh coal.

Raw Coal Topsize--

The net capital investment and annual revenue requirement effects of coal cleaning are quite sensitive to raw coal topsize. For a change from 3 inches to 1-1/2 inches in the raw coal topsize, the net capital investment benefit of coal cleaning drops from $2.7M to $0.7M. For the same cases, the annual revenue requirement benefit drops from $3M to $2.2M. The smaller size reduces the efficiency of the dense-medium separations and increases the quantity cleaned in the less efficient froth flotation process, reducing Btu recovery. The smaller topsize also results in a slightly lower heating value because of the higher percentage of coal cleaned by the less efficient equipment, such as the froth flotation cells. Therefore, more coal must be processed which results in increased equipment size and cost.

Transportation Distance--

Transportation distance is the shipping distance of the raw or cleaned coals to the power plant, and is used to determine an annual revenue requirement benefit for using cleaned coal. The sensitivity of the net levelized annual revenue requirements to transportation distance is shown in Table 15. The net annual revenue requirements are quite insensitive to transportation distance. For example, a 50% increase in distance will decrease the annual revenue requirements by less than 3%. It is apparent that transportation distance has only a minor affect on net annual revenue requirements.

TABLE 15. NET LEVELIZED ANNUAL REVENUE REQUIREMENTS AT VARIOUS TRANSPORTATION DISTANCES

| Distance, miles | Levelized annual revenue requirements, 1984$ M$ | Levelized annual revenue requirements, 1984$ % change |
|---|---|---|
| 250 | -7.1 | +2.7 |
| 500 (base) | -7.3 | - |
| 750 | -7.5 | -2.7 |

Coal Type--

Figure 15 illustrates the reduction in levelized annual revenue requirements for the four coals at different $SO_2$ emission limits as compared to sulfur removal with FGD alone. Significant differences in levelized annual revenue requirements result from differences in coal washability. Also, the economics generally become more favorable as the $SO_2$ emission limits become less stringent; however, the curves for the Cedar Grove and Upper Freeport coals do have a maximum point beyond which the economics become less favorable. These maxima are located at the points where the optimum pollution control process changes from a combined coal-cleaning - FGD process to a coal-cleaning process, alone. In the cases of the curves for the Illinois No. 6 and Pittsburgh coals, these curves did not reach the point at which coal cleaning could provide the most economical pollution control process without some degree of FGD being necessary.

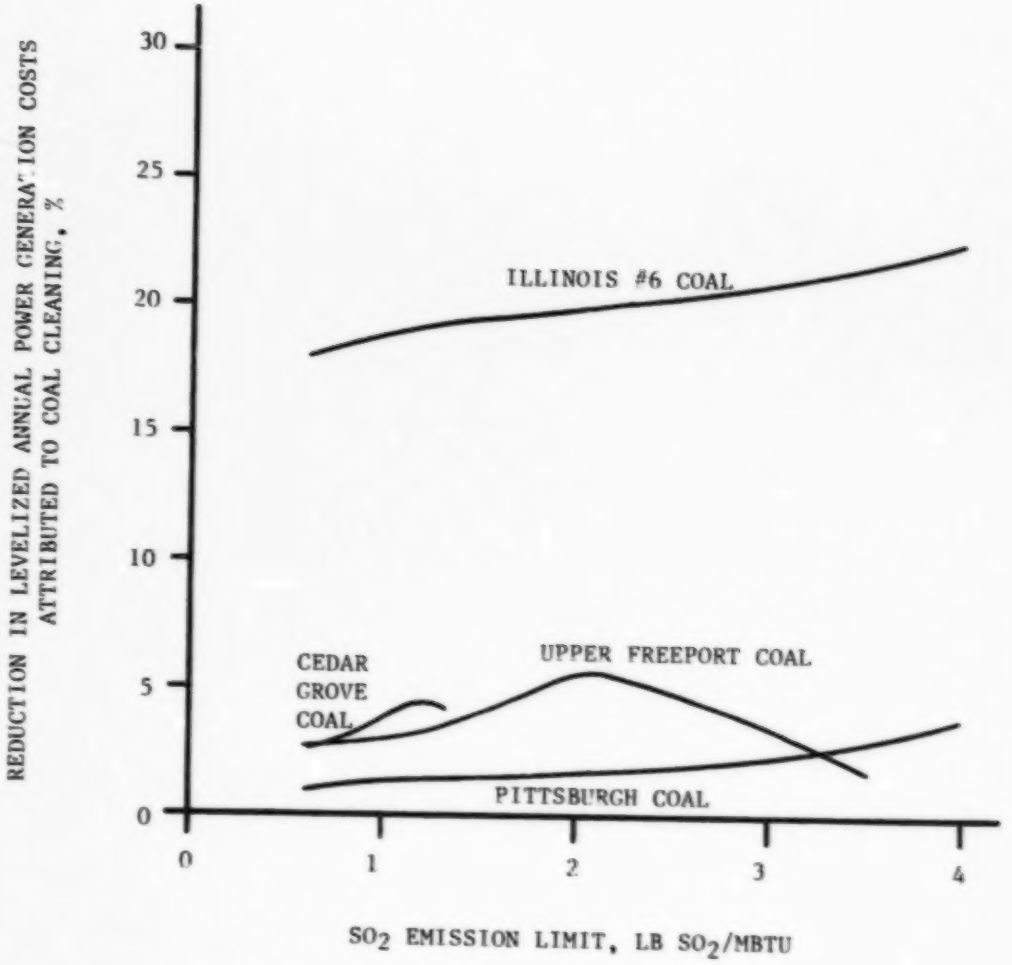

Figure 15. Effect of emission limit on the power generation cost reduction attributable to coal cleaning (at optimum specific gravity).

## PROJECT CONCLUSIONS AND RECOMMENDATIONS

A coal-cleaning computer program and a computer program that determines the economic benefits and penalties of using cleaned coal were combined with an FGD economics computer model to create a combined model capable of calculating the economics of coal-cleaning processes alone and combined with FGD in utility applications.

Selected values obtained from illustrative runs of the combined model have been compared against corresponding values obtained from manual calculations and have shown excellent agreement.

In the illustrative runs, coal cleaning removed 14% to 57% of the sulfur in four premise coals and met some of the less stringent emission limits by itself. Coal cleaning reduced FGD costs in all cases, primarily by allowing more flue gas to be bypassed; however, a case-by-case comparison is needed to determine if the reduction in FGD costs and other cost benefits offsets the cost of coal cleaning. Generally, FGD alone was higher in capital investment than the combined process except in select cases with the more stringent emission limits and less stringent cleaning levels (higher specific gravities of separation). FGD alone was higher in capital investment in all cases with the less stringent emission limits and more stringent cleaning levels (lower specific gravities of separation). The combined process had lower annual revenue requirements than FGD alone in all cases except two with the most stringent emission and cleaning levels.

For the cases studied, it was found that the use of coal cleaning in combination with FGD can have a varied effect on the levelized annual cost of power production. This effect, which is dependent on the coal and the specific operating conditions, ranges from a 0.5% increase to a 22.6% decrease in those costs.

The sum of all economic benefits and penalties associated with the use of cleaned coal in a combined coal-cleaning - FGD system changed the capital investment of the coal-cleaning plant between a reduction of $136M and an increase of $7.6M as compared with FGD alone, depending on the conditions used. The same effects changed the levelized annual revenue requirements between a reduction of $134M per year and an increase of $2.9M per year.

Studies should be made to more accurately define the effects of coal cleaning on power production. In particular, improvements are needed in the relationship used in the economic benefits and penalties program to determine

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the effect of coal cleaning on power plant availability, peaking capacity, and rated capacity.

A baghouse option should be added to the benefits and penalties program. This would be useful in cases involving low-sulfur coals.

The coal-cleaning program should be used in conjunction with other programs that have been or are being developed to simulate other pollution control processes, e.g., a spray dryer model, a coal gasification model, or a fluidized-bed combustion model. The program should also be used to simulate other coal-cleaning process designs in addition to the one used in this project by developing the necessary cost and operating performance data.

The combined model should be revised periodically to ensure that the performance and economic data remain up-to-date. This is particularly easy for the coal-cleaning program, in which most of this information is input data, but changes in the other programs might require some programming knowledge.

A programming modification should be made to the coal-cleaning program to produce more than one simulation per run. This would facilitate the determination of operating conditions that produce the minimum costs by decreasing the amount of trial and error comparisons required.

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# Appendix

## TABLE A-1. WASHABILITY DATA FOR THE PITTSBURGH COAL

| | | | Direct, % | | | | | Cumulative, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Size fraction and weight | Specific gravity | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 4.2 inches by 2.97 inches | FLOAT-1.30 | 6.80 | 4.56 | 0.70 | 2.17 | 14,622 | 6.80 | 4.56 | 0.70 | 2.17 | 14,622 |
| % of flow: 3.4 | 1.30-1.35 | 65.00 | 6.12 | 1.78 | 2.38 | 14,383 | 71.80 | 5.97 | 1.68 | 2.36 | 14,406 |
| | 1.35-1.40 | 8.20 | 11.90 | 3.81 | 5.24 | 13,263 | 80.00 | 6.58 | 1.90 | 2.66 | 14,289 |
| | 1.40-1.50 | 9.80 | 21.95 | 3.91 | 5.34 | 11,602 | 89.80 | 8.26 | 2.12 | 2.95 | 13,995 |
| | 1.50-1.60 | 4.30 | 28.68 | 4.06 | 5.49 | 10,486 | 94.10 | 9.19 | 2.20 | 3.06 | 13,835 |
| | 1.60-1.90 | 1.70 | 40.69 | 4.50 | 5.93 | 8,486 | 95.80 | 9.75 | 2.25 | 3.12 | 13,740 |
| | 1.90-2.20 | 2.50 | 55.78 | 8.70 | 10.13 | 5,794 | 98.30 | 10.92 | 2.41 | 3.29 | 13,538 |
| | 2.20-2.50 | 0.80 | 70.20 | 9.95 | 11.38 | 3,357 | 99.10 | 11.40 | 2.47 | 3.36 | 13,456 |
| | 2.50-2.80 | 0.40 | 66.58 | 12.84 | 14.27 | 3,811 | 99.50 | 11.62 | 2.51 | 3.40 | 13,417 |
| | 2.80-SINK | 0.50 | 60.38 | 37.31 | 38.61 | 3,369 | 100.00 | 11.86 | 2.69 | 3.58 | 13,367 |
| 2.97 inches by 1.495 inches | FLOAT-1.30 | 9.41 | 4.14 | 0.66 | 2.14 | 14,692 | 9.41 | 4.14 | 0.66 | 2.14 | 14,692 |
| % of flow: 12.4 | 1.30-1.35 | 58.06 | 6.01 | 1.59 | 3.08 | 14,339 | 67.47 | 5.75 | 1.46 | 2.95 | 14,388 |
| | 1.35-1.40 | 8.71 | 11.42 | 3.40 | 4.88 | 13,358 | 76.18 | 6.40 | 1.68 | 3.17 | 14,270 |
| | 1.40-1.50 | 9.81 | 20.09 | 3.90 | 5.38 | 11,905 | 85.99 | 7.96 | 1.94 | 3.42 | 14,001 |
| | 1.50-1.60 | 3.90 | 27.75 | 4.11 | 5.59 | 10,633 | 89.89 | 8.82 | 2.03 | 3.52 | 13,854 |
| | 1.60-1.90 | 4.00 | 41.21 | 4.81 | 6.30 | 8,381 | 93.89 | 10.20 | 2.15 | 3.63 | 13,621 |
| | 1.90-2.20 | 1.90 | 62.75 | 8.49 | 9.97 | 4,652 | 95.80 | 11.24 | 2.27 | 3.76 | 13,443 |
| | 2.20-2.50 | 2.60 | 71.86 | 9.54 | 11.02 | 3,100 | 98.40 | 12.85 | 2.47 | 3.95 | 13,169 |
| | 2.50-2.80 | 0.90 | 69.79 | 11.91 | 13.39 | 3,324 | 99.30 | 13.36 | 2.55 | 4.04 | 13,080 |
| | 2.80-SINK | 0.70 | 61.06 | 36.52 | 37.93 | 3,289 | 100.00 | 13.70 | 2.79 | 4.28 | 13,011 |
| 1.495 inches by 0.742 inch | FLOAT-1.30 | 14.30 | 3.93 | 0.65 | 1.98 | 14,739 | 14.30 | 3.93 | 0.65 | 1.98 | 14,739 |
| % of flow: 21.2 | 1.30-1.35 | 53.40 | 6.21 | 1.45 | 2.84 | 14,320 | 67.70 | 5.73 | 1.28 | 2.66 | 14,408 |
| | 1.35-1.40 | 9.80 | 10.87 | 3.10 | 4.34 | 13,483 | 77.50 | 6.38 | 1.51 | 2.87 | 14,291 |
| | 1.40-1.50 | 8.50 | 18.74 | 3.94 | 5.08 | 12,153 | 86.00 | 7.60 | 1.75 | 3.09 | 14,080 |
| | 1.50-1.60 | 4.00 | 27.75 | 3.98 | 4.96 | 10,681 | 90.00 | 8.50 | 1.85 | 3.17 | 13,929 |
| | 1.60-1.90 | 3.90 | 42.14 | 4.43 | 5.17 | 8,308 | 93.90 | 9.89 | 1.96 | 3.26 | 13,696 |
| | 1.90-2.20 | 2.70 | 66.16 | 8.28 | 8.60 | 4,195 | 96.60 | 11.47 | 2.13 | 3.40 | 13,430 |
| | 2.20-2.50 | 1.50 | 75.79 | 9.28 | 9.64 | 2,557 | 98.10 | 12.45 | 2.24 | 3.50 | 13,264 |
| | 2.50-2.80 | 1.10 | 75.69 | 11.31 | 11.76 | 2,466 | 99.20 | 13.15 | 2.34 | 3.59 | 13,144 |
| | 2.80-SINK | 0.80 | 61.44 | 35.63 | 37.55 | 3,229 | 100.00 | 13.54 | 2.61 | 3.86 | 13,065 |
| 0.742 onch by 0.371 inch | FLOAT-1.30 | 22.40 | 4.04 | 0.69 | 2.12 | 14,712 | 22.40 | 4.04 | 0.69 | 2.12 | 14,712 |
| % of flow: 21.4 | 1.30-1.35 | 46.60 | 6.21 | 1.38 | 2.65 | 14,333 | 69.00 | 5.51 | 1.16 | 2.48 | 14,456 |
| | 1.35-1.40 | 9.10 | 10.66 | 2.92 | 4.21 | 13,521 | 78.10 | 6.11 | 1.36 | 2.68 | 14,347 |
| | 1.40-1.50 | 8.20 | 17.71 | 4.02 | 5.53 | 12,289 | 86.30 | 7.21 | 1.61 | 2.95 | 14,152 |
| | 1.50-1.60 | 3.70 | 27.13 | 4.48 | 5.76 | 10,734 | 90.00 | 8.03 | 1.73 | 3.07 | 14,011 |
| | 1.60-1.90 | 3.90 | 41.83 | 5.95 | 6.79 | 8,276 | 93.90 | 9.43 | 1.91 | 3.22 | 13,773 |
| | 1.90-2.20 | 2.50 | 68.13 | 6.12 | 6.45 | 3,977 | 96.40 | 10.95 | 2.02 | 3.30 | 13,519 |
| | 2.20-2.50 | 1.70 | 79.21 | 7.47 | 7.91 | 2,077 | 98.10 | 12.14 | 2.11 | 3.38 | 13,321 |
| | 2.50-2.80 | 1.40 | 80.14 | 7.59 | 8.11 | 1,911 | 99.50 | 13.09 | 2.19 | 3.45 | 13,160 |
| | 2.80-SINK | 0.50 | 61.50 | 33.08 | 35.63 | 3,554 | 100.00 | 13.34 | 2.34 | 3.61 | 13,112 |

(Continued)

TABLE A-1. (Continued)

| Size fraction and weight | Specific gravity | Weight | Direct, %<br>Ash | Direct, %<br>Pyritic sulfur | Direct, %<br>Total sulfur | Btu/lb | Cumulative, %<br>Weight | Cumulative, %<br>Ash | Cumulative, %<br>Pyritic sulfur | Cumulative, %<br>Total sulfur | Btu/lb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.371 inch by 28 mesh | FLOAT-1.30 | 24.10 | 3.11 | 0.55 | 1.84 | 14,883 | 24.10 | 3.11 | 0.55 | 1.84 | 14,883 |
| % of flow: 37.1 | 1.30-1.35 | 38.90 | 5.90 | 1.29 | 2.55 | 14,390 | 63.00 | 4.83 | 1.01 | 2.28 | 14,579 |
|  | 1.35-1.40 | 10.50 | 9.84 | 2.79 | 4.09 | 13,664 | 73.50 | 5.55 | 1.26 | 2.54 | 14,448 |
|  | 1.40-1.50 | 7.10 | 15.95 | 4.17 | 5.19 | 12,613 | 80.60 | 6.46 | 1.52 | 2.77 | 14,286 |
|  | 1.50-1.60 | 3.10 | 25.06 | 5.28 | 6.92 | 11,006 | 83.70 | 7.15 | 1.66 | 2.92 | 14,165 |
|  | 1.60-1.90 | 6.30 | 48.46 | 6.05 | 6.81 | 7,185 | 90.00 | 10.04 | 1.96 | 3.20 | 13,676 |
|  | 1.90-2.20 | 2.80 | 65.33 | 5.31 | 5.87 | 4,459 | 92.80 | 11.71 | 2.07 | 3.28 | 13,398 |
|  | 2.20-2.50 | 4.00 | 82.83 | 5.26 | 5.51 | 1,605 | 96.80 | 14.65 | 2.20 | 3.37 | 12,911 |
|  | 2.50-2.80 | 2.50 | 86.77 | 4.63 | 4.77 | 997 | 99.30 | 16.47 | 2.26 | 3.40 | 12,611 |
|  | 2.80-SINK | 0.70 | 64.20 | 31.09 | 33.05 | 3,258 | 100.00 | 16.80 | 2.46 | 3.61 | 12,545 |
| 28 mesh by 0 inch | FLOAT-1.30 | 33.20 | 3.00 | 0.62 | 1.91 | 14,898 | 33.20 | 3.00 | 0.62 | 1.91 | 14,898 |
| % of flow: 4.5 | 1.30-1.35 | 20.70 | 6.42 | 1.17 | 2.77 | 14,281 | 53.90 | 4.31 | 0.83 | 2.24 | 14,661 |
|  | 1.35-1.40 | 7.90 | 9.22 | 2.24 | 3.60 | 13,788 | 61.80 | 4.94 | 1.01 | 2.41 | 14,549 |
|  | 1.40-1.50 | 6.70 | 14.08 | 3.11 | 4.64 | 12,930 | 68.50 | 5.83 | 1.22 | 2.63 | 14,391 |
|  | 1.50-1.60 | 4.40 | 21.95 | 4.64 | 5.60 | 11,605 | 72.90 | 6.81 | 1.42 | 2.81 | 14,223 |
|  | 1.60-1.90 | 6.70 | 37.38 | 6.18 | 6.91 | 9,007 | 79.60 | 9.38 | 1.82 | 3.16 | 13,784 |
|  | 1.90-2.20 | 3.80 | 59.12 | 6.59 | 7.02 | 5,430 | 83.40 | 11.65 | 2.04 | 3.33 | 13,403 |
|  | 2.20-2.50 | 5.60 | 78.79 | 4.34 | 4.64 | 2,311 | 89.00 | 15.87 | 2.19 | 3.41 | 12,705 |
|  | 2.50-2.80 | 8.40 | 87.60 | 3.49 | 3.96 | 890 | 97.40 | 22.06 | 2.30 | 3.46 | 11,686 |
|  | 2.80-SINK | 2.60 | 69.48 | 28.93 | 29.77 | 2,587 | 100.00 | 23.29 | 2.99 | 4.15 | 11,450 |
| Composite | FLOAT-1.30 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 |
| % of feed: 100.0 | 1.30-1.35 | 46.05 | 6.08 | 1.42 | 2.72 | 14,350 | 65.72 | 5.32 | 1.18 | 2.49 | 14,486 |
|  | 1.35-1.40 | 9.64 | 10.44 | 2.96 | 4.27 | 13,555 | 75.35 | 5.97 | 1.40 | 2.72 | 14,367 |
|  | 1.40-1.50 | 8.04 | 17.76 | 3.99 | 5.25 | 12,303 | 83.39 | 7.11 | 1.65 | 2.96 | 14,168 |
|  | 1.50-1.60 | 3.62 | 26.48 | 4.56 | 5.90 | 10,833 | 87.01 | 7.92 | 1.77 | 3.09 | 14,030 |
|  | 1.60-1.90 | 4.86 | 44.72 | 5.62 | 6.47 | 7,815 | 91.87 | 9.86 | 1.98 | 3.27 | 13,701 |
|  | 1.90-2.20 | 2.64 | 65.14 | 6.59 | 7.16 | 4,428 | 94.50 | 11.40 | 2.11 | 3.37 | 13,442 |
|  | 2.20-2.50 | 2.77 | 79.78 | 6.47 | 6.92 | 2,032 | 97.27 | 13.35 | 2.23 | 3.48 | 13,117 |
|  | 2.50-2.80 | 1.97 | 83.51 | 6.12 | 6.50 | 1,441 | 99.24 | 14.74 | 2.31 | 3.54 | 12,886 |
|  | 2.80-SINK | 0.76 | 63.58 | 32.81 | 34.59 | 3,195 | 100.00 | 15.11 | 2.54 | 3.77 | 12,812 |

## TABLE A-2. WASHABILITY DATA FOR THE ILLINOIS NO. 6 COAL

| Size fraction and weight | Specific gravity | Weight | Direct, % |  |  |  | Cumulative, % |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 4.2 inches by 2.97 inches<br>% of flow: 3.4 | FLOAT-1.30 | 14.90 | 4.46 | 0.82 | 2.43 | 14,536 | 14.90 | 4.46 | 0.82 | 2.43 | 14,536 |
|  | 1.30-1.35 | 28.20 | 7.91 | 1.18 | 2.80 | 13,923 | 43.10 | 6.72 | 1.06 | 2.67 | 14,135 |
|  | 1.35-1.40 | 12.10 | 13.28 | 1.97 | 3.24 | 12,985 | 55.20 | 8.16 | 1.26 | 2.80 | 13,883 |
|  | 1.40-1.50 | 7.90 | 18.65 | 3.16 | 4.70 | 11,974 | 63.10 | 9.47 | 1.49 | 3.03 | 13,644 |
|  | 1.50-1.60 | 2.70 | 24.53 | 5.36 | 6.80 | 10,855 | 65.80 | 10.09 | 1.65 | 3.19 | 13,529 |
|  | 1.60-1.90 | 6.20 | 37.51 | 10.17 | 11.00 | 8,421 | 72.00 | 12.45 | 2.39 | 3.86 | 13,090 |
|  | 1.90-2.20 | 2.50 | 57.48 | 13.80 | 14.22 | 4,824 | 74.50 | 13.96 | 2.77 | 4.21 | 12,812 |
|  | 2.20-2.50 | 8.00 | 84.96 | 5.55 | 5.74 | 533 | 82.50 | 20.84 | 3.04 | 4.36 | 11,621 |
|  | 2.50-2.80 | 14.70 | 98.00 | 0.77 | 1.14 | 35 | 97.20 | 32.51 | 2.70 | 3.87 | 9,869 |
|  | 2.80-SINK | 2.80 | 66.07 | 32.93 | 32.93 | 2,389 | 100.00 | 33.45 | 3.54 | 4.68 | 9,660 |
| 2.97 inches by 1.495 inches<br>% of flow: 12.4 | FLOAT-1.30 | 16.80 | 4.46 | 0.79 | 2.40 | 14,538 | 16.80 | 4.46 | 0.79 | 2.40 | 14,538 |
|  | 1.30-1.35 | 26.90 | 8.01 | 1.18 | 2.79 | 13,906 | 43.70 | 6.65 | 1.03 | 2.64 | 14,149 |
|  | 1.35-1.40 | 11.70 | 13.28 | 1.94 | 3.19 | 12,988 | 55.40 | 8.05 | 1.22 | 2.76 | 13,904 |
|  | 1.40-1.50 | 7.80 | 18.86 | 3.08 | 4.60 | 11,945 | 63.20 | 9.38 | 1.45 | 2.98 | 13,662 |
|  | 1.50-1.60 | 2.90 | 24.64 | 5.13 | 6.55 | 10,851 | 66.10 | 10.05 | 1.61 | 3.14 | 13,539 |
|  | 1.60-1.90 | 6.30 | 37.92 | 9.56 | 10.40 | 8,381 | 72.40 | 12.48 | 2.30 | 3.77 | 13,090 |
|  | 1.90-2.20 | 2.60 | 57.68 | 12.95 | 13.43 | 4,828 | 75.00 | 14.04 | 2.67 | 4.11 | 12,803 |
|  | 2.20-2.50 | 7.90 | 84.25 | 5.35 | 5.64 | 657 | 82.90 | 20.73 | 2.93 | 4.25 | 11,646 |
|  | 2.50-2.80 | 14.40 | 96.97 | 1.75 | 2.12 | 49 | 97.30 | 32.02 | 2.75 | 3.94 | 9,930 |
|  | 2.80-SINK | 2.70 | 66.22 | 32.85 | 32.85 | 2,368 | 100.00 | 32.94 | 3.57 | 4.72 | 9,725 |
| 1.495 inches by 0.742 inch<br>% of flow: 21.2 | FLOAT-1.30 | 11.40 | 4.36 | 0.72 | 2.24 | 14,567 | 11.40 | 4.36 | 0.72 | 2.24 | 14,567 |
|  | 1.30-1.35 | 23.10 | 8.31 | 1.04 | 2.61 | 13,865 | 34.50 | 7.00 | 0.93 | 2.49 | 14,097 |
|  | 1.35-1.40 | 12.50 | 13.28 | 1.62 | 3.17 | 12,979 | 47.00 | 8.67 | 1.12 | 2.67 | 13,800 |
|  | 1.40-1.50 | 8.50 | 18.86 | 2.63 | 4.47 | 11,940 | 55.50 | 10.23 | 1.35 | 2.94 | 13,515 |
|  | 1.50-1.60 | 3.70 | 24.43 | 4.35 | 6.24 | 10,885 | 59.20 | 11.12 | 1.54 | 3.15 | 13,350 |
|  | 1.60-1.90 | 8.50 | 39.13 | 9.28 | 10.20 | 8,179 | 67.70 | 14.64 | 2.51 | 4.04 | 12,701 |
|  | 1.90-2.20 | 3.60 | 60.02 | 11.13 | 11.75 | 4,508 | 71.30 | 16.93 | 2.94 | 4.43 | 12,287 |
|  | 2.20-2.50 | 10.50 | 84.55 | 4.40 | 5.03 | 625 | 81.80 | 25.61 | 3.13 | 4.50 | 10,790 |
|  | 2.50-2.80 | 14.60 | 93.47 | 2.07 | 2.48 | 55 | 96.40 | 35.89 | 2.97 | 4.20 | 9,165 |
|  | 2.80-SINK | 3.60 | 66.82 | 32.45 | 32.45 | 2,284 | 100.00 | 37.00 | 4.03 | 5.21 | 8,917 |
| 0.742 inch by 0.371 inch<br>% of flow: 21.4 | FLOAT-1.30 | 25.83 | 4.46 | 0.72 | 2.42 | 14,534 | 25.83 | 4.46 | 0.72 | 2.42 | 14,534 |
|  | 1.30-1.35 | 25.23 | 8.72 | 1.26 | 2.90 | 13,777 | 51.05 | 6.56 | 0.99 | 2.66 | 14,160 |
|  | 1.35-1.40 | 9.71 | 13.79 | 2.02 | 3.60 | 12,869 | 60.76 | 7.72 | 1.15 | 2.81 | 13,954 |
|  | 1.40-1.50 | 7.01 | 19.67 | 3.16 | 4.34 | 11,830 | 67.77 | 8.96 | 1.36 | 2.97 | 13,734 |
|  | 1.50-1.60 | 3.10 | 25.14 | 5.05 | 5.94 | 10,813 | 70.87 | 9.66 | 1.52 | 3.10 | 13,606 |
|  | 1.60-1.90 | 5.21 | 39.33 | 7.83 | 8.70 | 8,224 | 76.08 | 11.69 | 1.95 | 3.48 | 13,238 |
|  | 1.90-2.20 | 2.90 | 56.97 | 11.65 | 12.19 | 5,013 | 78.98 | 13.36 | 2.31 | 3.80 | 12,936 |
|  | 2.20-2.50 | 5.81 | 82.12 | 5.33 | 5.66 | 1,022 | 84.78 | 18.07 | 2.52 | 3.93 | 12,120 |
|  | 2.50-2.80 | 13.31 | 93.07 | 1.74 | 1.86 | 62 | 98.10 | 28.25 | 2.41 | 3.65 | 10,483 |
|  | 2.80-SINK | 1.90 | 67.17 | 32.19 | 32.19 | 2,239 | 100.00 | 28.99 | 2.98 | 4.19 | 10,327 |

(Continued)

TABLE A-2. (Continued)

| | | | Direct, % | | | | | Cumulative, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Size fraction and weight | Specific gravity | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 0.371 inch by 28 mesh | FLOAT-1.30 | 34.50 | 4.16 | 0.78 | 2.35 | 14,594 | 34.50 | 4.16 | 0.78 | 2.35 | 14,594 |
| % of flow: 37.1 | 1.30-1.35 | 21.20 | 8.11 | 1.28 | 2.85 | 13,887 | 55.70 | 5.66 | 0.97 | 2.54 | 14,325 |
| | 1.35-1.40 | 9.30 | 12.88 | 2.02 | 3.35 | 13,048 | 65.00 | 6.70 | 1.12 | 2.66 | 14,142 |
| | 1.40-1.50 | 6.30 | 18.25 | 2.77 | 4.12 | 12,081 | 71.30 | 7.72 | 1.27 | 2.79 | 13,960 |
| | 1.50-1.60 | 3.30 | 26.05 | 3.84 | 4.95 | 10,700 | 74.60 | 8.53 | 1.38 | 2.88 | 13,816 |
| | 1.60-1.90 | 4.90 | 38.22 | 5.65 | 6.41 | 8,538 | 79.50 | 10.36 | 1.64 | 3.10 | 13,491 |
| | 1.90-2.20 | 2.40 | 57.89 | 8.16 | 8.96 | 5,013 | 81.90 | 11.75 | 1.83 | 3.27 | 13,242 |
| | 2.20-2.50 | 4.30 | 78.97 | 4.82 | 5.57 | 1,554 | 86.20 | 15.10 | 1.98 | 3.39 | 12,659 |
| | 2.50-2.80 | 11.90 | 88.40 | 1.92 | 2.63 | 82 | 98.10 | 24.00 | 1.98 | 3.29 | 11,133 |
| | 2.80-SINK | 1.90 | 65.04 | 34.24 | 34.24 | 2,499 | 100.00 | 24.77 | 2.59 | 3.88 | 10,969 |
| 28 mesh 0 inch | FLOAT-1.30 | 34.60 | 4.16 | 0.50 | 2.05 | 14,611 | 34.60 | 4.16 | 0.50 | 2.05 | 14,611 |
| % of flow: 4.5 | 1.30-1.35 | 11.30 | 9.83 | 1.13 | 2.64 | 13,603 | 45.90 | 5.56 | 0.66 | 2.20 | 14,363 |
| | 1.35-1.40 | 8.00 | 13.89 | 1.47 | 2.97 | 12,886 | 53.90 | 6.79 | 0.78 | 2.31 | 14,144 |
| | 1.40-1.50 | 6.90 | 19.77 | 2.03 | 3.50 | 11,846 | 60.80 | 8.27 | 0.92 | 2.45 | 13,883 |
| | 1.50-1.60 | 5.40 | 26.05 | 2.38 | 3.67 | 10,760 | 66.20 | 9.72 | 1.04 | 2.55 | 13,628 |
| | 1.60-1.90 | 8.10 | 43.29 | 3.01 | 4.02 | 7,779 | 74.30 | 13.38 | 1.25 | 2.71 | 12,991 |
| | 1.90-2.20 | 4.90 | 61.44 | 3.28 | 4.40 | 4,626 | 79.20 | 16.35 | 1.38 | 2.81 | 12,473 |
| | 2.20-2.50 | 7.20 | 77.25 | 2.92 | 4.33 | 1,893 | 86.40 | 21.43 | 1.51 | 2.94 | 11,591 |
| | 2.50-2.80 | 11.10 | 75.63 | 1.66 | 1.92 | 2,337 | 97.50 | 27.60 | 1.52 | 2.82 | 10,538 |
| | 2.80-SINK | 2.50 | 66.10 | 29.65 | 29.79 | 2,543 | 100.00 | 28.56 | 2.23 | 3.50 | 10,338 |
| Composite | FLOAT-1.30 | 24.90 | 4.28 | 0.74 | 2.34 | 14,573 | 24.90 | 4.28 | 0.74 | 2.34 | 14,573 |
| % of feed: 100.0 | 1.30-1.35 | 22.95 | 8.31 | 1.20 | 2.79 | 13,854 | 47.85 | 6.21 | 0.96 | 2.56 | 14,228 |
| | 1.35-1.40 | 10.40 | 13.27 | 1.89 | 3.31 | 12,978 | 58.25 | 7.47 | 1.13 | 2.69 | 14,005 |
| | 1.40-1.50 | 7.18 | 18.86 | 2.84 | 4.31 | 11,961 | 65.44 | 8.72 | 1.32 | 2.87 | 13,781 |
| | 1.50-1.60 | 3.37 | 25.30 | 4.27 | 5.57 | 10,790 | 68.80 | 9.53 | 1.46 | 3.00 | 13,634 |
| | 1.60-1.90 | 6.09 | 38.94 | 7.62 | 8.47 | 8,304 | 74.90 | 11.93 | 1.96 | 3.45 | 13,201 |
| | 1.90-2.20 | 2.90 | 58.49 | 10.01 | 10.68 | 4,824 | 77.80 | 13.66 | 2.26 | 3.72 | 12,888 |
| | 2.20-2.50 | 6.64 | 82.37 | 4.79 | 5.36 | 986 | 84.44 | 19.07 | 2.46 | 3.85 | 11,952 |
| | 2.50-2.80 | 13.14 | 91.64 | 1.84 | 2.28 | 152 | 97.58 | 28.84 | 2.38 | 3.64 | 10,363 |
| | 2.80-SINK | 2.42 | 66.21 | 32.87 | 32.88 | 2,367 | 100.00 | 29.74 | 3.11 | 4.34 | 10,170 |

## TABLE A-3. WASHABILITY DATA FOR THE UPPER FREEPORT COAL

| | | | Direct, % | | | | | Cumulative, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Size fraction and weight | Specific gravity | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 4.2 inches by 2.97 inches | FLOAT-1.30 | 3.10 | 4.98 | 0.64 | 1.24 | 15,321 | 3.10 | 4.98 | 0.64 | 1.24 | 15,321 |
| % of flow: 3.4 | 1.30-1.35 | 28.80 | 9.11 | 1.18 | 1.90 | 14,600 | 31.90 | 8.71 | 1.13 | 1.84 | 14,670 |
| | 1.35-1.40 | 20.00 | 15.68 | 1.19 | 1.73 | 13,525 | 51.90 | 11.40 | 1.15 | 1.80 | 14,229 |
| | 1.40-1.50 | 14.90 | 21.61 | 1.60 | 2.28 | 12,510 | 66.80 | 13.67 | 1.25 | 1.90 | 13,845 |
| | 1.50-1.60 | 5.30 | 31.04 | 2.36 | 2.81 | 10,928 | 72.10 | 14.95 | 1.33 | 1.97 | 13,631 |
| | 1.60-1.90 | 13.10 | 48.83 | 3.42 | 3.85 | 7,926 | 85.20 | 20.16 | 1.65 | 2.26 | 12,754 |
| | 1.90-2.20 | 1.40 | 59.11 | 10.07 | 10.68 | 5,877 | 86.60 | 20.79 | 1.79 | 2.40 | 12,643 |
| | 2.20-2.50 | 2.40 | 76.48 | 7.82 | 8.59 | 3,095 | 89.00 | 22.29 | 1.95 | 2.56 | 12,385 |
| | 2.50-2.80 | 10.60 | 93.33 | 3.31 | 3.56 | 570 | 99.60 | 29.85 | 2.10 | 2.67 | 11,128 |
| | 2.80-SINK | 0.40 | 65.15 | 34.54 | 35.08 | 3,664 | 100.00 | 29.99 | 2.23 | 2.80 | 11,098 |
| 2.97 inches by 1.495 inches | FLOAT-1.30 | 12.20 | 4.77 | 0.60 | 1.21 | 15,358 | 12.20 | 4.77 | 0.60 | 1.21 | 15,358 |
| % of flow: 12.4 | 1.30-1.35 | 24.40 | 9.00 | 1.12 | 1.83 | 14,621 | 36.60 | 7.59 | 0.95 | 1.62 | 14,867 |
| | 1.35-1.40 | 18.60 | 15.47 | 1.15 | 1.71 | 13,561 | 55.20 | 10.25 | 1.02 | 1.65 | 14,427 |
| | 1.40-1.50 | 13.80 | 21.29 | 1.58 | 2.25 | 12,564 | 69.00 | 12.45 | 1.13 | 1.77 | 14,054 |
| | 1.50-1.60 | 5.00 | 30.40 | 2.35 | 2.80 | 11,034 | 74.00 | 13.67 | 1.21 | 1.84 | 13,850 |
| | 1.60-1.90 | 12.10 | 47.88 | 3.51 | 3.91 | 8,082 | 86.10 | 18.47 | 1.53 | 2.13 | 13,039 |
| | 1.90-2.20 | 1.30 | 58.47 | 9.86 | 10.42 | 5,996 | 87.40 | 19.07 | 1.66 | 2.26 | 12,935 |
| | 2.20-2.50 | 2.20 | 75.42 | 8.05 | 8.76 | 3,264 | 89.60 | 20.45 | 1.81 | 2.42 | 12,697 |
| | 2.50-2.80 | 9.80 | 92.69 | 3.53 | 3.78 | 664 | 99.40 | 27.58 | 1.98 | 2.55 | 11,511 |
| | 2.80-SINK | 0.60 | 65.04 | 30.42 | 35.36 | 3,522 | 100.00 | 27.80 | 2.15 | 2.75 | 11,463 |
| 1.495 inches by 0.742 inch | FLOAT-1.30 | 25.00 | 4.77 | 0.62 | 1.21 | 15,359 | 25.00 | 4.77 | 0.60 | 1.21 | 15,359 |
| % of flow: 21.2 | 1.30-1.35 | 16.10 | 8.47 | 1.14 | 1.78 | 14,714 | 41.10 | 6.22 | 0.82 | 1.43 | 15,106 |
| | 1.35-1.40 | 14.90 | 14.72 | 0.92 | 1.53 | 13,691 | 56.00 | 8.48 | 0.85 | 1.46 | 14,730 |
| | 1.40-1.50 | 11.90 | 21.19 | 1.36 | 1.86 | 12,606 | 67.90 | 10.71 | 0.94 | 1.53 | 14,358 |
| | 1.50-1.60 | 5.20 | 29.87 | 1.74 | 2.08 | 11,161 | 73.10 | 12.07 | 1.00 | 1.57 | 14,130 |
| | 1.60-1.90 | 12.20 | 43.64 | 2.09 | 2.39 | 8,863 | 85.30 | 16.59 | 1.15 | 1.69 | 13,377 |
| | 1.90-2.20 | 1.20 | 59.11 | 8.72 | 8.96 | 5,974 | 86.50 | 17.18 | 1.26 | 1.79 | 13,274 |
| | 2.20-2.50 | 2.20 | 76.80 | 6.92 | 7.47 | 3,105 | 88.70 | 18.66 | 1.40 | 1.93 | 13,022 |
| | 2.50-2.80 | 10.30 | 92.16 | 3.27 | 3.63 | 756 | 99.00 | 26.30 | 1.59 | 2.10 | 11,746 |
| | 2.80-SINK | 1.00 | 67.69 | 35.69 | 35.69 | 3,236 | 100.00 | 26.72 | 1.93 | 2.44 | 11,661 |
| 0.742 inch by 0.371 inch | FLOAT-1.30 | 37.90 | 4.03 | 0.52 | 1.14 | 15,483 | 37.90 | 4.03 | 0.52 | 1.14 | 15,483 |
| % of flow: 21.4 | 1.35-1.40 | 13.40 | 14.41 | 1.25 | 1.78 | 13,734 | 73.50 | 7.33 | 0.77 | 1.41 | 14,922 |
| | 1.40-1.50 | 9.10 | 20.76 | 1.72 | 2.39 | 12,644 | 82.60 | 8.81 | 0.88 | 1.52 | 14,671 |
| | 1.50-1.60 | 2.90 | 28.18 | 2.67 | 3.16 | 11,383 | 85.50 | 9.47 | 0.94 | 1.57 | 14,560 |
| | 1.60-1.90 | 6.40 | 45.66 | 3.82 | 4.27 | 8,432 | 91.90 | 11.99 | 1.14 | 1.76 | 14,133 |
| | 1.90-2.20 | 1.30 | 55.19 | 9.06 | 9.90 | 6,557 | 93.20 | 12.59 | 1.25 | 1.87 | 14,028 |
| | 2.20-2.50 | 1.20 | 72.25 | 8.77 | 9.53 | 3,751 | 94.40 | 13.35 | 1.35 | 1.97 | 13,897 |
| | 2.50-2.80 | 4.80 | 91.42 | 4.00 | 4.07 | 867 | 99.20 | 17.13 | 1.47 | 2.07 | 13,266 |
| | 2.80-SINK | 0.80 | 63.24 | 32.70 | 34.95 | 3,930 | 100.00 | 17.49 | 1.72 | 2.34 | 13,192 |

(Continued)

TABLE A-3. (Continued)

| | | | Direct, % | | | | | Cumulative, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Size fraction and weight | Specific gravity | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 0.371 inch by 28 mesh | FLOAT-1.30 | 51.90 | 3.81 | 0.32 | 0.93 | 15,529 | 51.90 | 3.81 | 0.32 | 0.93 | 15,529 |
| % of flow: 37.1 | 1.30-1.35 | 18.40 | 8.58 | 0.75 | 1.44 | 14,711 | 70.30 | 5.06 | 0.43 | 1.06 | 15,315 |
| | 1.35-1.40 | 9.20 | 13.67 | 1.13 | 1.66 | 13,863 | 79.50 | 6.06 | 0.51 | 1.13 | 15,147 |
| | 1.40-1.50 | 6.30 | 19.17 | 1.81 | 2.36 | 12,914 | 85.80 | 7.02 | 0.61 | 1.22 | 14,983 |
| | 1.50-1.60 | 2.60 | 26.80 | 3.02 | 3.47 | 11,597 | 88.40 | 7.60 | 0.68 | 1.29 | 14,883 |
| | 1.60-1.90 | 4.30 | 47.35 | 6.47 | 6.80 | 8,028 | 92.70 | 9.44 | 0.95 | 1.54 | 14,565 |
| | 1.90-2.20 | 1.30 | 55.08 | 10.61 | 10.73 | 6,558 | 94.00 | 10.07 | 1.08 | 1.67 | 14,455 |
| | 2.20-2.50 | 1.10 | 70.76 | 11.72 | 11.83 | 3,904 | 95.10 | 10.78 | 1.20 | 1.79 | 14,333 |
| | 2.50-2.80 | 3.40 | 88.88 | 5.92 | 6.19 | 1,176 | 98.50 | 13.47 | 1.37 | 1.94 | 13,878 |
| | 2.80-SINK | 1.50 | 62.50 | 36.25 | 38.83 | 3,849 | 100.00 | 14.21 | 1.89 | 2.49 | 13,728 |
| 28 mesh by 0 inch | FLOAT-1.30 | 57.40 | 2.65 | 0.29 | 0.90 | 15,724 | 57.40 | 2.65 | 0.29 | 0.90 | 15,724 |
| % of flow: 4.5 | 1.30-1.35 | 13.80 | 7.10 | 0.54 | 1.10 | 14,978 | 71.20 | 3.51 | 0.34 | 0.94 | 15,579 |
| | 1.35-1.40 | 6.80 | 12.92 | 0.83 | 1.41 | 13,996 | 78.00 | 4.33 | 0.38 | 0.98 | 15,441 |
| | 1.40-1.50 | 5.10 | 18.43 | 1.51 | 1.78 | 13,075 | 83.10 | 5.20 | 0.45 | 1.03 | 15,296 |
| | 1.50-1.60 | 3.20 | 22.88 | 2.09 | 2.40 | 12,305 | 86.30 | 5.85 | 0.51 | 1.08 | 15,185 |
| | 1.60-1.90 | 4.40 | 34.85 | 3.32 | 3.52 | 10,268 | 90.70 | 7.26 | 0.65 | 1.20 | 14,947 |
| | 1.90-2.20 | 1.70 | 51.59 | 6.63 | 6.69 | 7,340 | 92.40 | 8.08 | 0.76 | 1.30 | 14,807 |
| | 2.20-2.50 | 1.20 | 68.11 | 9.66 | 9.70 | 4,451 | 93.60 | 8.85 | 0.87 | 1.41 | 14,674 |
| | 2.50-2.80 | 3.70 | 86.33 | 5.61 | 5.78 | 1,621 | 97.30 | 11.79 | 1.07 | 1.57 | 14,178 |
| | 2.80-SINK | 2.70 | 65.47 | 34.86 | 37.81 | 3,396 | 100.00 | 13.24 | 1.96 | 2.55 | 13,887 |
| Composite | FLOAT-1.30 | 36.89 | 3.96 | 0.42 | 1.03 | 15,501 | 36.89 | 3.96 | 0.42 | 1.03 | 15,501 |
| % of feed: 100.0 | 1.30-1.35 | 19.61 | 8.63 | 0.93 | 1.62 | 14,694 | 56.50 | 5.58 | 0.60 | 1.23 | 15,221 |
| | 1.35-1.40 | 12.73 | 14.51 | 1.10 | 1.66 | 13,722 | 69.22 | 7.22 | 0.69 | 1.31 | 14,945 |
| | 1.40-1.50 | 9.25 | 20.56 | 1.61 | 2.19 | 12,691 | 78.47 | 8.79 | 0.80 | 1.41 | 14,679 |
| | 1.50-1.60 | 3.63 | 28.63 | 2.39 | 2.81 | 11,327 | 82.11 | 9.67 | 0.87 | 1.48 | 14,531 |
| | 1.60-1.90 | 7.69 | 45.66 | 3.69 | 4.05 | 8,444 | 89.80 | 12.75 | 1.11 | 1.70 | 14,010 |
| | 1.90-2.20 | 1.30 | 56.25 | 9.56 | 9.93 | 6,396 | 91.10 | 13.38 | 1.23 | 1.81 | 13,901 |
| | 2.20-2.50 | 1.54 | 73.87 | 8.85 | 9.34 | 3,500 | 92.64 | 14.38 | 1.36 | 1.94 | 13,728 |
| | 2.50-2.80 | 6.21 | 91.38 | 4.05 | 4.31 | 854 | 98.85 | 19.22 | 1.53 | 2.09 | 12,919 |
| | 2.80-SINK | 1.15 | 64.08 | 35.07 | 37.29 | 3,676 | 100.00 | 19.74 | 1.91 | 2.49 | 12,813 |

## TABLE A-4. WASHABILITY DATA FOR THE CEDAR GROVE COAL

| | | | Direct, % | | | | Cumulative, % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Size fraction and weight | Specific gravity | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb | Weight | Ash | Pyritic sulfur | Total sulfur | Btu/lb |
| 4.2 inches by 1.249 inches | FLOAT-1.40 | 71.96 | 3.28 | 0.00 | 0.88 | 14,622 | 71.96 | 3.28 | 0.00 | 0.88 | 14,622 |
| % of flow: 20.7 | 1.40-1.50 | 3.55 | 19.95 | 0.00 | 1.37 | 12,087 | 75.51 | 4.06 | 0.00 | 0.90 | 14,503 |
| | 1.50-1.60 | 1.84 | 29.08 | 0.00 | 1.39 | 10,699 | 77.35 | 4.66 | 0.00 | 0.91 | 14,412 |
| | 1.60-1.80 | 1.73 | 38.99 | 0.00 | 1.04 | 9,193 | 79.08 | 5.41 | 0.00 | 0.92 | 14,298 |
| | 1.80-1.90 | 1.62 | 48.21 | 0.00 | 0.51 | 7,792 | 80.70 | 6.27 | 0.00 | 0.91 | 14,168 |
| | 1.90-2.00 | 1.00 | 57.42 | 0.00 | 0.51 | 6,392 | 81.70 | 6.90 | 0.00 | 0.90 | 14,072 |
| | 2.00-SINK | 18.30 | 85.93 | 0.00 | 0.51 | 2,023 | 100.00 | 21.36 | 0.00 | 0.83 | 11,867 |
| 1.249 inches by 0.371 inch | FLOAT-1.40 | 75.64 | 3.58 | 0.00 | 0.86 | 14,576 | 75.64 | 3.58 | 0.00 | 0.86 | 14,576 |
| % of flow: 37.7 | 1.40-1.50 | 2.82 | 19.75 | 0.00 | 1.60 | 12,118 | 78.46 | 4.16 | 0.00 | 0.89 | 14,488 |
| | 1.50-1.60 | 1.66 | 29.46 | 0.00 | 1.60 | 10,642 | 80.12 | 4.69 | 0.00 | 0.90 | 14,408 |
| | 1.60-1.80 | 1.79 | 38.65 | 0.00 | 1.34 | 9,246 | 81.91 | 5.43 | 0.00 | 0.91 | 14,295 |
| | 1.80-1.90 | 1.08 | 48.46 | 0.00 | 0.85 | 7,754 | 82.99 | 5.99 | 0.00 | 0.91 | 14,210 |
| | 1.90-2.00 | 0.58 | 57.61 | 0.00 | 0.85 | 6,363 | 83.57 | 6.35 | 0.00 | 0.91 | 14,156 |
| | 2.00-SINK | 16.43 | 83.52 | 0.00 | 0.85 | 2,394 | 100.00 | 19.03 | 0.00 | 0.90 | 12,223 |
| 0.371 inch by 1/4 inch | FLOAT-1.40 | 78.61 | 4.01 | 0.00 | 0.84 | 14,512 | 78.61 | 4.01 | 0.00 | 0.84 | 14,512 |
| % of flow: 10.0 | 1.40-1.50 | 2.11 | 19.22 | 0.00 | 1.70 | 12,501 | 80.72 | 4.41 | 0.00 | 0.86 | 14,459 |
| | 1.50-1.60 | 1.58 | 29.38 | 0.00 | 1.85 | 10,655 | 82.30 | 4.89 | 0.00 | 0.88 | 14,386 |
| | 1.60-1.80 | 1.60 | 37.32 | 0.00 | 1.56 | 9,450 | 83.90 | 5.51 | 0.00 | 0.89 | 14,292 |
| | 1.80-1.90 | 0.89 | 47.84 | 0.00 | 0.94 | 7,848 | 84.79 | 5.95 | 0.00 | 0.89 | 14,225 |
| | 1.90-2.00 | 0.49 | 56.88 | 0.00 | 0.99 | 6,475 | 85.28 | 6.24 | 0.00 | 0.90 | 14,180 |
| | 2.00-SINK | 14.72 | 83.02 | 0.00 | 0.99 | 2,471 | 100.00 | 17.54 | 0.00 | 0.91 | 12,457 |
| 1/4 inch by 28 mesh | FLOAT-1.40 | 81.60 | 4.43 | 0.00 | 0.82 | 14,447 | 81.60 | 4.43 | 0.00 | 0.82 | 14,447 |
| % of flow: 27.1 | 1.40-1.50 | 1.40 | 18.68 | 0.00 | 1.80 | 12,883 | 83.00 | 4.67 | 0.00 | 0.84 | 14,421 |
| | 1.50-1.60 | 1.50 | 29.31 | 0.00 | 2.09 | 10,667 | 84.50 | 5.11 | 0.00 | 0.86 | 14,354 |
| | 1.60-1.80 | 1.40 | 35.98 | 0.00 | 1.78 | 9,653 | 85.90 | 5.61 | 0.00 | 0.87 | 14,277 |
| | 1.80-1.90 | 0.70 | 47.22 | 0.00 | 1.12 | 7,942 | 86.60 | 5.95 | 0.00 | 0.88 | 14,226 |
| | 1.90-2.00 | 0.40 | 56.14 | 0.00 | 1.12 | 6,586 | 87.00 | 6.18 | 0.00 | 0.88 | 14,191 |
| | 2.00-SINK | 13.00 | 82.52 | 0.00 | 1.12 | 2,548 | 100.00 | 16.10 | 0.00 | 0.91 | 12,677 |
| 28 mesh by 0 inch | FLOAT-1.40 | 84.54 | 4.68 | 0.00 | 0.80 | 14,409 | 84.54 | 4.68 | 0.00 | 0.80 | 14,409 |
| % of flow: 4.5 | 1.40-1.50 | 0.83 | 18.50 | 0.00 | 1.98 | 12,311 | 85.37 | 4.81 | 0.00 | 0.81 | 14,389 |
| | 1.50-1.60 | 1.36 | 29.59 | 0.00 | 2.26 | 10,625 | 86.73 | 5.20 | 0.00 | 0.83 | 14,330 |
| | 1.60-1.80 | 1.42 | 35.64 | 0.00 | 2.02 | 9,705 | 88.15 | 5.69 | 0.00 | 0.85 | 14,255 |
| | 1.80-1.90 | 0.27 | 47.37 | 0.00 | 1.38 | 7,919 | 88.42 | 5.82 | 0.00 | 0.85 | 14,236 |
| | 1.90-2.00 | 0.09 | 56.24 | 0.00 | 1.38 | 6,571 | 88.51 | 5.87 | 0.00 | 0.86 | 14,228 |
| | 2.00-SINK | 11.49 | 80.67 | 0.00 | 1.38 | 2,832 | 100.00 | 14.47 | 0.00 | 0.92 | 12,919 |
| Composite | FLOAT-1.40 | 77.20 | 3.86 | 0.00 | 0.85 | 14,533 | 77.20 | 3.86 | 0.00 | 0.85 | 14,533 |
| % of feed: 100.0 | 1.40-1.50 | 2.42 | 19.58 | 0.00 | 1.58 | 12,265 | 79.62 | 4.34 | 0.00 | 0.87 | 14,464 |
| | 1.50-1.60 | 1.63 | 29.33 | 0.00 | 1.72 | 10,662 | 81.25 | 4.84 | 0.00 | 0.89 | 14,388 |
| | 1.60-1.80 | 1.64 | 37.86 | 0.00 | 1.42 | 9,367 | 82.89 | 5.50 | 0.00 | 0.90 | 14,289 |
| | 1.80-1.90 | 1.03 | 48.08 | 0.00 | 0.80 | 7,811 | 83.92 | 6.02 | 0.00 | 0.90 | 14,209 |
| | 1.90-2.00 | 0.59 | 57.20 | 0.00 | 0.80 | 6,425 | 84.51 | 6.38 | 0.00 | 0.90 | 14,155 |
| | 2.00-SINK | 15.49 | 83.74 | 0.00 | 0.86 | 2,361 | 100.00 | 18.36 | 0.00 | 0.89 | 12,328 |

## TABLE A-5. EXAMPLE INPUT DATA FOR THE BASE CASE (LONG FORM)

```
================================================================================
LINE TYPE                         EXAMPLE INPUT DATA
--------------------------------------------------------------------------------

            COL
             1
    1        1 1 0 0 1 2
    2        1 1 1 1 1
    3        1 1 1 1 1 1 1 1 1 0 0 0
    4        1 0 1 0
    5        PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO) 1.60 SPG
    6        BITUMINOUS, 3.67% SULFUR, 3" TOPSIZE, 1.20 LB SO2/MBTU SIP
    7        2 1000 9200 12121 39 300 2 1 1 86.8 175 470 751.9
    8P       35.83 46.94 1.52 0.1 13.81 2.15 2.57 0.95 92 80 2 0.86 0.03
    9        90 20 5 10 25 2 1.200 10 0 1.3 1 0 .15 0 1000 2 4.85 5 0.0 0.0
   10        15 40 1.2 40 0 30 0.0 40 1.2 7.0 0 9 0 14.7 1
   11        1 0 3 0 35 0.0000005 32 10 5.7 1 8 2 0.1
   12        1 0 9999 5600 25 25 5280 1 12 6
   13        6 1 14 4 12 8 15.6 10 7 3 60 1.086 14.7 0
   14        1 4 3.5 6 0 1 1.5 1 2 1 8 5 10 0 21
   15        0.50 75 460 1200 15 2.5 .14 .037 21 20.81 1.6 107.35 336.1 245.5 1982 1984 0
   16        4 1 5 0.8 1.0 3 .65 1 1 1.1 1982 297.9
   17        6 55 7.97 297.9 342.6 1 0.5 500 0.75
   18        6
   19        STREAM BLENDER
   20        41 1 0
   19        WET UPPER SCREEN
   20        23 3 0
   22        2 9 1
   23        10.0     6.0     1.5     0.375   0.25    0.093   0.0232  0.0164  0.0116
   24P       60.0     60.0    60.0    60.0    50.0    50.0    60.0    60.0    60.0
   19        DENSE-MEDIUM VESSEL
   20        2 4 0
   21A       0.0
   22        6 5 1
   23        100.0 0.0
   24D       7.98E-30 67.0  14.39  -13.59  59.0
--------------------------------------------------------------------------------
```

(Continued)

## TABLE A-5. (Continued)

```
==================================================================================================
LINE TYPE                                  EXAMPLE INPUT DATA
--------------------------------------------------------------------------------------------------

            COL
             1
 25D         40.0    0.90    0.975   1.02    1.14
 19          DENSE-MEDIUM CYCLONE
 20          3 4 0
 21A         0.0
 22          6 5 1
 23          100.0 0.0
 24D         3.22E-27 61.0   11.86   -11.36  60.0
 25D         47.0     0.90   0.965   1.030   1.14
 19          FROTH FLOTATION CELL
 20          7 6 0
 21          1.0
 22          2 20 7
 23             .8200    .8800    .8900    .9000    .9140    .9248    .9330    .9360    .9536    .9700
 23            1.0000   1.0310   1.0660   1.0710   1.0850   1.0900   1.1000   1.1110   1.3000   1.5000
 24            1.0000    .9930    .9870    .3780    .9600    .9400    .9200    .9000    .6000    .6900
 24             .5000    .3000    .0800    .0600    .0430    .0330    .0260    .0230    .0110   0.0000
 23             .8340    .8560    .8700    .8800    .8900    .9020    .9100    .9370    .9490    .9700
 23            1.0000   1.0350   1.0450   1.0690   1.0900   1.1160   1.1400   1.1680   1.2000   1.5560
 24            1.0600    .9970    .9930    .9870    .9770    .9630    .9400    .9000    .8000    .6750
 24             .5000    .3000    .2400    .1800    .0990    .0600    .0400    .0260    .0160   0.0000
 23             .7050    .8500    .8650    .8850    .9000    .9200    .9300    .9750   1.0000   1.0500
 23            1.0600   1.0950   1.1200   1.1500   1.2000   1.2600   1.7000   1.8000   1.9000   2.0000
 24            1.0000    .9976    .9940    .9810    .9600    .9200    .8000    .6350    .5000    .2790
 24             .1480    .1000    .0680    .0460    .0253    .0100   0.0000   0.0000   0.0000   0.0000
 23             .7590    .8200    .8300    .8500    .8650    .8750    .8900    .9100    .9300   1.0000
 23            1.0700   1.0900   1.1200   1.1600   1.2050   1.3250   1.4750   1.6690   1.8000   2.0000
 24            1.0000    .9930    .9910    .9830    .9720    .9620    .9390    .8870    .8170    .5000
 24             .2460    .1950    .1450    .1030    .0733    .0400    .0150   0.0000   0.0000   0.0000
 23             .7310    .7600     7800    .8090    .8400    .8620    .9000   1.0000   1.1200   1.1600
 23            1.2000   1.2600   1.3000   1.3630   1.6000   1.8000   2.0000   2.0500   2.1000   2.1500
 24            1.0000    .9940    .9670    .9680    .9320    .9000    .8000    .5000    .2000    .1350
--------------------------------------------------------------------------------------------------
```

(Continued)

## TABLE A-5. (Continued)

```
================================================================================
LINE TYPE                         EXAMPLE INPUT DATA
--------------------------------------------------------------------------------

            COL
             1
 24            .0990   .0660   .0520   .0400   .0263   .0210   .0200   .0200   .0200   .0200
 23            .6630   .7200   .7800   .8200   .8620   .8840   .9160  1.0060  1.0260  1.0400
 23           1.0790  1.1200  1.2200  1.2400  1.2700  1.3200  1.3800  2.0000  2.0500  2.1000
 24           1.0000   .9770   .9410   .9093   .9622   .8230   .7560   .5000   .4200   .3750
 24            .3100   .2370   .1900   .0960   .0603   .0400   .0300   .0200   .0200   .0200
 23            .6360   .6400   .6800   .7240   .7600   .8000   .8360   .8520   .9000  1.0000
 23           1.0400  1.1240  1.2000  1.3200  1.4000  1.6000  2.0000  2.0500  2.1000  2.1500
 24           1.0000   .9980   .9920   .9810   .9690   .9470   .9190   .9030   .8000   .5000
 24            .4100   .3390   .2920   .2430   .2190   .1770   .1200   .1200   .1200   .1200
 19         PRIMARY SINGLE ROLL CRUSHER
 20         14 4 0
 21C        0.05 1.0 4.0
 22         2 11 1
 23         1.0 0.8306 0.5982 0.4176 0.2065 0.1041 0.0522 0.0360 0.0260 0.0131 0.0
 24         1.0 0.96 0.79 0.45 0.20 0.10 0.05 0.03 0.02 0.0 0.0
 30         CONF
 31         14 20
 32            14     2.970                           CRUSHER (OVERSIZE)
 32            23     0.371                           PREWET SCREEN
 32             2     1.60                            DENSE MEDIUM VESSEL
 32            41     2.25                            BLENDER (3 X 3/8 CLEAN COAL)
 32            41     6.00                            BLENDER (3 X 3/8 REFUSE)
 32            23     0.0232                          SCREEN (FINES)
 32             3     1.60                            DENSE MEDIUM CYCLONE
 32            41     5.25                            BLENDER (3/8 X 28 M CLEAN COAL)
 32            41     5.25                            BLENDER (3/8 X 28 M REFUSE)
 32             7                                     FROTH FLOTATION CELLS
 32            41     25.0                            BLENDER (28M X 0 CLEAN COAL)
 32            41     25.0                            BLENDER (28M X 0 REFUSE)
 32            41                                     BLENDER (CLEAN COAL)
 32            41                                     BLENDER (REFUSE)
--------------------------------------------------------------------------------
```

(Continued)

TABLE A-5. (Continued)

```
LINE TYPE                              EXAMPLE INPUT DATA

            COL
             1
  33            0     1
  33            1     2
  33            2     3 U
  33            2     6 L
  33            3     4 C
  33            3     5 R
  33            6     7 U
  33            6    10 L
  33            7     8 C
  33            7     9 R
  33           10    11 C
  33           10    12 R
  33            4    13 C
  33            8    13 C
  33           11    13 C
  33            5    14 R
  33            9    14 R
  33           12    14 R
  33           13     0 C
  33           14     0 R
  34                    (THIS BLANK LINE INDICATES NO MORE CONFIGURATIONS)
  35        6 10
  36        4.20 2.970 1.495 0.742 0.371 0.0232 0.0
  37        1.06 1.30 1.35 1.40 1.50 1.60 1.90 2.20 2.50 2.80 3.00
  38        COAL
  39        100 130 100 100 100 100
  40              6.80       4.56       0.70       2.17     14622.
  40             65.00       6.12       1.78       2.38     14383.
  40              8.20      11.90       3.01       5.24     13263.
  40              9.80      21.95       3.91       5.34     11602.
  40              4.30      28.68       4.86       5.49     10486.
  40              1.70      40.69       4.50       5.93      8486.
```

(Continued)

## TABLE A-5. (Continued)

```
=================================================================================================
=================================================================================================
LINE TYPE                                    EXAMPLE INPUT DATA
-------------------------------------------------------------------------------------------------
                                                   |
                 COL
                  1
   40                       2.50      55.78      6.70     10.13      5794.
   40                       0.80      70.20      9.95     11.38      3357.
   40                       0.40      65.58     12.94     14.27      3811.
   40                       0.50      60.38     37.31     38.61      3369.
   40                       9.40       4.14      0.66      2.14     14692.
   40                      58.00       6.01      1.59      3.08     14339.
   40                       8.70      11.42      3.40      4.89     13358.
   40                       9.80      20.09      3.90      5.38     11905.
   40                       3.90      27.75      4.11      5.59     10633.
   40                       4.00      41.21      4.81      6.30      8381.
   40                       1.90      62.75      6.49      9.97      4652.
   40                       2.60      71.86      9.54     11.02      3100.
   40                       0.90      69.79     11.91     13.39      3324.
   40                       0.70      61.06     36.52     37.93      3289.
   40                      14.30       3.93      0.65      1.98     14739.
   40                      53.40       6.21      1.45      2.84     14320.
   40                       9.80      10.87      3.10      4.34     13483.
   40                       8.50      18.74      3.94      5.08     12153.
   40                       4.00      27.75      3.98      4.96     10681.
   40                       3.90      42.14      4.43      5.17      8308.
   40                       2.70      66.16      8.28      8.60      4195.
   40                       1.50      75.79      9.28      9.64      2557.
   40                       1.10      75.69     11.31     11.75      2466.
   40                       0.80      61.44     35.63     37.55      3229.
   40                      22.40       4.04      0.69      2.12     14712.
   40                      46.60       6.21      1.38      2.65     14333.
   40                       9.10      10.66      2.92      4.21     13521.
   40                       8.20      17.71      4.02      5.53     12289.
   40                       3.70      27.13      4.48      5.76     10734.
   40                       3.90      41.83      5.95      6.79      8276.
   40                       2.50      68.13      6.12      6.45      3977.
-------------------------------------------------------------------------------------------------
```

(Continued)

## TABLE A-5. (Continued)

```
==================================================================================
LINE TYPE                              EXAMPLE INPUT DATA
----------------------------------------------------------------------------------

                 COL
                  1
40                  1.70     79.21      7.47      7.91     2077.
40                  1.40     80.14      7.59      8.11     1911.
40                  0.50     61.50     33.08     35.63     3554.
40                 24.10      3.11      0.55      1.84    14683.
43                 38.90      5.40      1.29      2.55    14390.
40                 10.50      9.84      2.79      4.07    13664.
40                  7.10     15.95      4.17      5.19    12613.
40                  3.10     25.06      5.28      6.92    11006.
40                  6.30     48.46      6.05      6.81     7185.
40                  2.80     65.33      5.31      5.87     4459.
40                  4.00     82.83      5.26      5.51     1605.
40                  2.50     86.77      4.63      4.77      997.
40                  0.70     64.20     31.09     33.05     3258.
40                 33.20      3.00      0.62      1.91    14698.
40                 20.70      6.42      1.17      2.77    14281.
40                  7.90      3.22      2.24      3.60    13788.
40                  6.70     14.08      3.11      4.64    12930.
40                  4.40     21.95      4.64      5.60    11605.
40                  6.70     37.38      6.18      6.91     9007.
40                  3.80     59.12      6.59      7.02     5430.
40                  5.60     78.79      4.34      4.64     2311.
40                  8.40     87.60      3.49      3.96      890.
40                  2.60     69.48     28.93     29.77     2587.
41                     (THIS BLANK LINE INDICATES NO MORE FEEDS)
42                CONF
43                COAL
44                  1 3    3    1    2          0.5      RAW COAL STORAGE
45                428.0 3600.0
44                  2 3    2    1    2          0.74     RAW COAL SIZING
45                836.0 1880.0
44                  3 3                                  COARSE COAL CLEANING
----------------------------------------------------------------------------------
```

(Continued)

## TABLE A-5. (Continued)

```
LINE TYPE                              EXAMPLE INPUT DATA
-------------------------------------------------------------------------------------------
             COL
              1
  44           4 4    2    5    2           0.53     CLEAN COAL HANDLING
  45          262.0 1695.0
  44           5 4    2    6    2           0.64     REFUSE HANDLING
  45          47.0 136.0
  44           6 3                                   INTERMEDIATE COAL CLEANING
  44           7 4    2    7    2           0.56     TOTAL COAL HANDLING
  45          458.0 898.0
  44           8 4    2    9    2           0.64     CLEAN COAL HANDLING
  45          384.0 1359.0
  44           9 4    2   10    2           0.64     REFUSE HANDLING
  45          75.0 342.0
  44          10 3                                   FINE COAL CLEANING
  44          11 4    2    8    2           0.72     TOTAL COAL HANDLING
  45          69.0 575.0
  44          12 4    2   11    2           0.54     CLEAN COAL HANDLING
  45          58.0 921.0
  44          13 4    2   12    2           0.43     REFUSE HANDLING
  45          11.0 1619.0
  44          14 3    3   20    2           0.71     REFUSE DISPOSAL
  45          143.0 3534.0
  44          15 3    3   19    2           0.50     CLEAN COAL STORAGE
  45          381.0 3402.0
  44          16 1    1                              TOTAL PROCESS CAPITAL
  46          -1
  47          862.0 24.0 1 0 0.2
  48          862.0 15110000.0 1 0 1.0
  49          143.0 145000.0 20 0 0.7
  56          862.0 2760.0 1 0 1.00
  51          862.0 4000.0 1 0 0.10
-------------------------------------------------------------------------------------------
```

## TABLE A-6. EXAMPLE INPUT DATA FOR THE BASE CASE (SHORT FORM)

```
==========================================================================================
LINE TYPE                                    EXAMPLE INPUT DATA
------------------------------------------------------------------------------------------

             COL
              1
   1          1 1 0 1 1 2
   2          1 1 1 1 1
   3          1 1 1 1 1 1 1 1 1 0 0 0
   4          1 0 1 0
   5          PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO) 1.60 SPG
   6          BITUMINOUS, 3.67% SULFUR, 3" TOPSIZE, 1.20 LB SO2/MBTU SIP
   7          2 1000 9200 12121 39 300 2 1 1 88.8 175 470 751.9
   8b         35.83 46.94 1.52 0.1 13.81 2.15 2.57 0.85 92 80 2 0.06 0.03
   9          90 20 5 10 25 2 1.200 10 0 1.3 1 0 .15 0 1000 3 4.65 5 0.0 0.0
  10          15 40 1.2 40 0 30 0.0 40 1.2 7.0 0 9 0 14.7 1
  11          1 0 3 0 35 0.0000005 32 10 5.7 1 8 2 0.1
  12          1 0 9999 5000 25 25 5280 1 12 6
  13          6 1 14 4 10 8 15.6 10 7 3 60 1.886 14.7 0
  14          1 4 3.5 6 0 1 1.5 1 2 1 8 5 10 0 21
  15          8.50 75 460 1200 15 2.5 .14 .037 21 20.81 1.6 107.35 336.1 245.5 1982 1984 0
  16          4 1 5 0.8 1.0 3 .65 1 1 1.1 1982 297.9
  17          6 55 2.97 297.9 342.6 1 0.5 500 0.75
  41          CONF
  42          COAL
  43            1 3    3    1    2           0.5       RAW COAL STORAGE
  44          428.0 3600.0
  43            2 3    2    1    2           0.74      RAW COAL SIZING
  44          836.0 1680.0
  43            3 3                                    COARSE COAL CLEANING
  43            4 4    2    5    2           0.53      CLEAN COAL HANDLING
  44          262.0 1695.0

------------------------------------------------------------------------------------------
```

(Continued)

## TABLE A-6. (Continued)

```
================================================================================
LINE TYPE                              EXAMPLE INPUT DATA
--------------------------------------------------------------------------------

             COL
              1
  43            5 4    2    6    2         0.64     REFUSE HANDLING
  44          47.0 136.0
  43            6 3                                 INTERMEDIATE COAL CLEANING
  43            7 4    2    7    2         0.56     TOTAL COAL HANDLING
  44          458.0 898.0
  43            8 4    2    9    2         0.64     CLEAN COAL HANDLING
  44          384.0 1359.0
  43            9 4    2   10    2         0.64     REFUSE HANDLING
  44          75.0 342.0
  43           10 3                                 FINE COAL CLEANING
  43           11 4    2    8    2         0.72     TOTAL COAL HANDLING
  44          69.0 575.0
  43           12 4    2   11    2         0.54     CLEAN COAL HANDLING
  44          58.0 921.0
  43           13 4    2   12    2         0.43     REFUSE HANDLING
  44          11.0 1619.0
  43           14 3    3   20    2         0.71     REFUSE DISPOSAL
  44          143.0 3534.0
  43           15 3    3   19    2         0.50     CLEAN COAL STORAGE
  44          381.0 3402.0
  43           16 1    1                            TOTAL PROCESS CAPITAL
  45           -1
  46          862.0 24.0 1 0 0.2
  47          862.0 15110000.0 1 0 1.0
  48          143.0 145000.0 20 0 0.7
  49          862.0 2760.0 1 0 1.00
  50          862.0 4000.0 1 0 0.10

--------------------------------------------------------------------------------
```

# TABLE A-7. EXAMPLE PRINTOUT FOR THE BASE CASE

```
                                          PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 1

COMBINED EXECUTION OF PROGRAMS FOR COAL CLEANING, FGD WITH PARTIAL SCRUBBING, AND ECONOMIC BENEFITS & PENALTIES


                                    TVA-EPA
                  COAL PREPARATION SIMULATION MODEL, CPSM4, VERSION 3
                     COMPUTERIZED DESIGN-COST ESTIMATE PROGRAM
                        REVISION DATE:  FEBRUARY 14, 1983


      CASE ID:    PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG
                  BITUMINOUS, 3.67% SULFUR, 3" TOPSIZE, 1.20 LB SO2/MBTU SIP

                                                    *** INPUTS ***

      RAW COAL CHARACTERISTICS
      --- ---- ---------------

      RAW COAL PROXIMATE ANALYSIS, WT% AS RECEIVED:

      VOLATILE MATTER = 35.83

      FIXED CARBON = 46.94

      RAW COAL ANALYSIS, WT % AS RECEIVED:

        C          H          O          N          S          CL       ASH        H2O
      65.35      4.42       7.87       1.35       3.67       0.10     13.81       3.42

      ORGANIC SULFUR CONTENT OF RAW COAL =  1.52 WT %, AS RECEIVED

      PYRITIC SULFUR CONTENT OF RAW COAL =  2.15 WT %, AS RECEIVED

      INTERNAL MOISTURE CONTENT OF RAW COAL =  2.57 WT %, AS RECEIVED

      SURFACE MOISTURE CONTENT OF RAW COAL =  0.85 WT %, AS RECEIVED

      HEAT CONTENT OF RAW COAL = 12121 BTU/LB, AS RECEIVED
```

(Continued)

## TABLE A-7. (Continued)

```
                                        PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SFG PAGE 2
POWER PLANT CHARACTERISTICS
----- ----- ---------------
PLANT SIZE =  1000 MEGAWATTS

POWER PLANT RATE =  9200 BTU/KWH

PLANT ON-STREAM TIME =  5500 HR/YR

PLANT LIFE =    30 YEARS



STACK SO2 EMISSION DATA
----- --- -------- ----
POTENTIAL COMBUSTION CONCENTRATION =  6.05 LBS SO2/M BTU

ACTUAL STACK EMISSION (BURNING RAW COAL) =  5.57 LBS SO2/M BTU

EMISSION STANDARD =  1.20 LBS SO2/MBTU
```

(Continued)

TABLE A-7. (Continued)

```
                                         PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 3

EQUIPMENT IDENTIFICATION
--------- --------------

UNIT NUMBER                 UNIT TYPE                      DECISION VARIABLES

     1               14 (CRUSHER (OVERSIZE))                     2.970

     2               23 (PREWET SCREEN)                          0.371

     3                2 (DENSE MEDIUM VESSEL)                    1.600

     4               41 (BLENDER (3 X 3/8 CLEAN COAL))

     5               41 (BLENDER (3 X 3/8 REFUSE))

     6               23 (SCREEN (FINES))                         0.023

     7                3 (DENSE MEDIUM CYCLONE)                   1.600

     8               41 (BLENDER (3/8 X 28 M CLEAN COAL))

     9               41 (BLENDER (3/8 X 28 M REFUSE))

    10                7 (FROTH FLOTATION CELLS)

    11               41 (BLENDER (28M X 0 CLEAN COAL))

    12               41 (BLENDER (28M X 0 REFUSE))

    13               41 (BLENDER (CLEAN COAL))

    14               41 (BLENDER (REFUSE))
```

(Continued)

# TABLE A-7. (Continued)

```
                                       PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 4

FLOWSTREAM IDENTIFICATION
---------- --------------

FLOWSTREAM NUMBER          ORIGIN - UNIT NUMBER          DESTINATION - UNIT NUMBER

      1  (FEED)                      0                                1
      2                              1                                2
      3                              2  U                             3
      4                              2  L                             6
      5                              3  C                             4
      6                              3  R                             5
      7                              6  U                             7
      8                              6  L                            10
      9                              7  C                             8
     10                              7  R                             9
     11                             10  C                            11
     12                             10  R                            12
     13                              4  C                            13
     14                              8  C                            13
     15                             11  C                            13
     16                              5  R                            14
     17                              9  R                            14
     18                             12  R                            14
     19  (CLEAN COAL PRODUCT)       13  C                             0
     20  (REFUSE PRODUCT)           14  R                             0
```

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 5

SPECIFIC GRAVITY ANALYSIS OF FLOWSTREAM NUMBER 1 (DRY BASIS)

FEED TO UNIT NUMBER 1

| SIZE FRACTION AND WEIGHT | SPECIFIC GRAVITY | DIRECT, PERCENT WEIGHT | ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB | CUMULATIVE, PERCENT WEIGHT | ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.2 BY 2.97 | FLOAT-1.30 | 6.80 | 4.56 | 0.70 | 2.17 | 14,622 | 6.80 | 4.56 | 0.70 | 2.17 | 14,622 |
| PERCENT OF FLOW 3.4 | 1.30-1.35 | 65.00 | 6.12 | 1.79 | 2.38 | 14,383 | 71.60 | 5.97 | 1.68 | 2.36 | 14,406 |
| | 1.35-1.40 | 8.20 | 11.90 | 3.81 | 5.24 | 13,263 | 80.00 | 6.58 | 1.93 | 2.66 | 14,289 |
| | 1.40-1.50 | 9.80 | 21.95 | 3.91 | 5.34 | 11,602 | 89.80 | 8.26 | 2.12 | 2.95 | 13,995 |
| | 1.50-1.60 | 4.30 | 28.68 | 4.06 | 5.49 | 10,486 | 94.10 | 9.19 | 2.20 | 3.06 | 13,835 |
| | 1.60-1.90 | 1.70 | 40.69 | 4.50 | 5.93 | 8,486 | 95.80 | 9.75 | 2.25 | 3.12 | 13,740 |
| | 1.90-2.20 | 2.50 | 55.78 | 8.70 | 10.13 | 5,794 | 98.30 | 10.92 | 2.41 | 3.29 | 13,536 |
| | 2.20-2.50 | 0.80 | 70.20 | 9.95 | 11.38 | 3,357 | 99.10 | 11.40 | 2.47 | 3.36 | 13,456 |
| | 2.50-2.80 | 0.40 | 66.58 | 12.84 | 14.27 | 3,811 | 99.50 | 11.62 | 2.51 | 3.40 | 13,417 |
| | 2.80-SINK | 0.50 | 60.38 | 37.31 | 38.61 | 3,369 | 100.00 | 11.86 | 2.69 | 3.58 | 13,367 |
| 2.97 BY 1.495 | FLOAT-1.30 | 9.41 | 4.14 | 0.66 | 2.14 | 14,692 | 9.41 | 4.14 | 0.66 | 2.14 | 14,692 |
| PERCENT OF FLOW 12.4 | 1.30-1.35 | 58.06 | 6.01 | 1.59 | 3.08 | 14,339 | 67.47 | 5.75 | 1.46 | 2.55 | 14,388 |
| | 1.35-1.40 | 8.71 | 11.42 | 3.40 | 4.88 | 13,358 | 76.18 | 6.40 | 1.68 | 3.17 | 14,270 |
| | 1.40-1.50 | 9.81 | 20.09 | 3.30 | 5.38 | 11,905 | 85.99 | 7.96 | 1.94 | 3.42 | 14,001 |
| | 1.50-1.60 | 3.90 | 27.75 | 4.11 | 5.59 | 10,633 | 89.89 | 8.82 | 2.03 | 3.52 | 13,854 |
| | 1.60-1.90 | 4.00 | 41.21 | 4.81 | 6.30 | 8,381 | 93.89 | 10.20 | 2.15 | 3.63 | 13,621 |
| | 1.90-2.20 | 1.90 | 62.75 | 8.49 | 9.97 | 4,652 | 95.80 | 11.24 | 2.27 | 3.76 | 13,443 |
| | 2.20-2.50 | 2.60 | 71.86 | 9.54 | 11.02 | 3,100 | 98.40 | 12.85 | 2.47 | 3.95 | 13,169 |
| | 2.50-2.80 | 0.90 | 69.79 | 11.91 | 13.39 | 3,324 | 99.30 | 13.36 | 2.55 | 4.04 | 13,060 |
| | 2.80-SINK | 0.78 | 61.06 | 36.52 | 37.93 | 3,289 | 100.00 | 13.70 | 2.79 | 4.28 | 13,011 |
| 1.495 BY 0.742 | FLOAT-1.30 | 14.30 | 3.93 | 0.55 | 1.98 | 14,739 | 14.30 | 3.93 | 0.65 | 1.98 | 14,739 |
| PERCENT OF FLOW 21.2 | 1.30-1.35 | 53.40 | 6.21 | 1.45 | 2.84 | 14,320 | 67.70 | 5.73 | 1.28 | 2.66 | 14,408 |
| | 1.35-1.40 | 9.80 | 10.87 | 3.10 | 4.34 | 13,483 | 77.50 | 6.38 | 1.51 | 2.87 | 14,291 |
| | 1.40-1.50 | 8.50 | 18.74 | 3.94 | 5.08 | 12,153 | 86.00 | 7.60 | 1.75 | 3.09 | 14,060 |
| | 1.50-1.60 | 4.00 | 27.75 | 3.98 | 4.96 | 10,681 | 90.00 | 8.50 | 1.85 | 3.17 | 13,929 |
| | 1.60-1.90 | 3.90 | 42.14 | 4.43 | 5.17 | 8,308 | 93.90 | 9.69 | 1.96 | 3.25 | 13,696 |
| | 1.90-2.20 | 2.70 | 66.16 | 8.28 | 8.60 | 4,195 | 96.60 | 11.47 | 2.13 | 3.40 | 13,430 |
| | 2.20-2.50 | 1.50 | 75.79 | 9.28 | 9.64 | 2,557 | 98.10 | 12.45 | 2.24 | 3.50 | 13,264 |
| | 2.50-2.80 | 1.10 | 75.69 | 11.31 | 11.76 | 2,466 | 99.20 | 13.15 | 2.34 | 3.59 | 13,144 |
| | 2.80-SINK | 0.80 | 61.44 | 35.63 | 37.55 | 3,229 | 100.00 | 13.54 | 2.61 | 3.86 | 13,665 |
| 0.742 BY 0.371 | FLOAT-1.30 | 22.40 | 4.04 | 0.69 | 2.12 | 14,712 | 22.40 | 4.04 | 0.69 | 2.12 | 14,712 |
| PERCENT OF FLOW 21.4 | 1.30-1.35 | 46.60 | 6.21 | 1.38 | 2.65 | 14,333 | 69.00 | 5.51 | 1.16 | 2.48 | 14,456 |
| | 1.35-1.40 | 9.10 | 10.66 | 2.92 | 4.21 | 13,521 | 78.10 | 6.11 | 1.36 | 2.68 | 14,347 |
| | 1.40-1.50 | 8.20 | 17.71 | 4.02 | 5.53 | 12,289 | 86.30 | 7.21 | 1.61 | 2.95 | 14,152 |
| | 1.50-1.60 | 3.70 | 27.13 | 4.48 | 5.76 | 10,734 | 90.00 | 8.03 | 1.73 | 3.07 | 14,011 |
| | 1.60-1.90 | 3.90 | 41.83 | 5.95 | 6.79 | 8,276 | 93.90 | 9.43 | 1.91 | 3.22 | 13,773 |
| | 1.90-2.20 | 2.50 | 68.13 | 6.12 | 6.45 | 3,977 | 96.40 | 10.95 | 2.02 | 3.30 | 13,519 |
| | 2.20-2.50 | 1.70 | 79.21 | 7.47 | 7.91 | 2,077 | 98.10 | 12.14 | 2.11 | 3.38 | 13,321 |
| | 2.50-2.80 | 1.40 | 80.14 | 7.59 | 8.11 | 1,911 | 99.50 | 13.09 | 2.19 | 3.45 | 13,160 |
| | 2.80-SINK | 0.50 | 61.50 | 33.38 | 35.63 | 3,554 | 100.00 | 13.34 | 2.34 | 3.61 | 13,112 |

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 6

SPECIFIC GRAVITY ANALYSIS OF FLOWSTREAM NUMBER 1 (CONTINUED)

FEED TO UNIT NUMBER 1

| SIZE FRACTION AND WEIGHT | SPECIFIC GRAVITY | DIRECT, PERCENT WEIGHT | DIRECT, PERCENT ASH | DIRECT, PERCENT PYRITIC SULFUR | DIRECT, PERCENT TOTAL SULFUR | DIRECT, PERCENT BTU/LB | CUMULATIVE, PERCENT WEIGHT | CUMULATIVE, PERCENT ASH | CUMULATIVE, PERCENT PYRITIC SULFUR | CUMULATIVE, PERCENT TOTAL SULFUR | CUMULATIVE, PERCENT BTU/LB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.371 BY 28M<br>PERCENT OF FLOW 37.1 | FLOAT-1.30 | 24.10 | 3.11 | 0.55 | 1.64 | 14,883 | 24.10 | 3.11 | 0.55 | 1.64 | 14,883 |
| | 1.30-1.35 | 38.90 | 5.90 | 1.29 | 2.55 | 14,390 | 63.00 | 4.83 | 1.01 | 2.28 | 14,579 |
| | 1.35-1.40 | 10.50 | 9.84 | 2.79 | 4.09 | 13,664 | 73.50 | 5.55 | 1.26 | 2.54 | 14,448 |
| | 1.40-1.50 | 7.10 | 15.95 | 4.17 | 5.19 | 12,613 | 80.60 | 6.46 | 1.52 | 2.77 | 14,286 |
| | 1.50-1.60 | 3.10 | 25.06 | 5.28 | 6.92 | 11,006 | 83.70 | 7.15 | 1.66 | 2.92 | 14,165 |
| | 1.60-1.90 | 6.30 | 48.46 | 6.05 | 6.81 | 7,185 | 90.00 | 10.04 | 1.96 | 3.20 | 13,676 |
| | 1.90-2.20 | 2.80 | 65.33 | 5.31 | 5.87 | 4,459 | 92.80 | 11.71 | 2.07 | 3.28 | 13,396 |
| | 2.20-2.50 | 4.00 | 82.83 | 5.26 | 5.51 | 1,685 | 96.80 | 14.65 | 2.20 | 3.37 | 12,911 |
| | 2.50-2.80 | 2.50 | 86.77 | 4.63 | 4.77 | 997 | 99.30 | 16.47 | 2.26 | 3.40 | 12,611 |
| | 2.80-SINK | 0.70 | 64.20 | 31.09 | 33.05 | 3,258 | 100.00 | 16.80 | 2.46 | 3.61 | 12,545 |
| 28M BY 0<br>PERCENT OF FLOW 4.5 | FLOAT-1.30 | 33.20 | 3.00 | 0.62 | 1.91 | 14,898 | 33.20 | 3.00 | 0.62 | 1.91 | 14,898 |
| | 1.30-1.35 | 20.70 | 6.42 | 1.17 | 2.77 | 14,281 | 53.90 | 4.31 | 0.83 | 2.24 | 14,661 |
| | 1.35-1.40 | 7.90 | 9.22 | 2.24 | 3.60 | 13,788 | 61.80 | 4.94 | 1.01 | 2.41 | 14,549 |
| | 1.40-1.50 | 6.70 | 14.08 | 3.11 | 4.64 | 12,930 | 68.50 | 5.83 | 1.22 | 2.63 | 14,391 |
| | 1.50-1.60 | 4.40 | 21.95 | 4.64 | 5.60 | 11,605 | 72.90 | 6.61 | 1.42 | 2.81 | 14,223 |
| | 1.60-1.90 | 6.70 | 37.38 | 6.18 | 6.91 | 9,007 | 79.60 | 9.38 | 1.82 | 3.16 | 13,784 |
| | 1.90-2.20 | 3.80 | 59.12 | 6.59 | 7.02 | 5,430 | 83.40 | 11.65 | 2.04 | 3.33 | 13,403 |
| | 2.20-2.50 | 5.60 | 78.79 | 4.34 | 4.64 | 2,311 | 89.00 | 15.87 | 2.19 | 3.41 | 12,705 |
| | 2.50-2.80 | 8.40 | 87.60 | 3.49 | 3.96 | 890 | 97.40 | 22.06 | 2.30 | 3.46 | 11,686 |
| | 2.80-SINK | 2.60 | 69.48 | 28.93 | 29.77 | 2,507 | 100.00 | 23.29 | 2.99 | 4.15 | 11,450 |
| COMPOSITE<br>PERCENT OF FEED 100.0 | FLOAT-1.30 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 |
| | 1.30-1.35 | 46.05 | 6.08 | 1.42 | 2.72 | 14,350 | 65.72 | 5.32 | 1.18 | 2.49 | 14,486 |
| | 1.35-1.40 | 9.64 | 10.44 | 2.96 | 4.27 | 13,555 | 75.35 | 5.97 | 1.40 | 2.72 | 14,367 |
| | 1.40-1.50 | 8.04 | 17.76 | 3.99 | 5.25 | 12,303 | 83.39 | 7.11 | 1.65 | 2.96 | 14,168 |
| | 1.50-1.60 | 3.62 | 26.48 | 4.36 | 5.98 | 10,833 | 87.01 | 7.92 | 1.77 | 3.09 | 14,030 |
| | 1.60-1.90 | 4.86 | 44.72 | 5.62 | 6.47 | 7,815 | 91.87 | 9.86 | 1.98 | 3.27 | 13,701 |
| | 1.90-2.20 | 2.64 | 65.14 | 6.59 | 7.16 | 4,428 | 94.50 | 11.40 | 2.11 | 3.37 | 13,442 |
| | 2.20-2.50 | 2.77 | 79.78 | 6.47 | 6.92 | 2,032 | 97.27 | 13.35 | 2.23 | 3.48 | 13,117 |
| | 2.50-2.80 | 1.97 | 83.51 | 6.12 | 6.50 | 1,441 | 99.24 | 14.74 | 2.31 | 3.54 | 12,886 |
| | 2.80-SINK | 0.76 | 63.59 | 32.81 | 34.59 | 3,195 | 100.00 | 15.11 | 2.54 | 3.77 | 12,812 |

(Continued)

TABLE A-7. (Continued)

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                                                   PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 7

                                    *** EXECUTION ***

SUMMARY OF THE PERFORMANCE CHARACTERISTICS OF UNIT NUMBER  1
------- -- --- ----------- --------------- -- ---- ------  -

                                   CRUSHER (OVERSIZE)
                              CRUSHER SETTING = 2.97 INCHES

SIZE, INCHES OR MESH                         4.2     2.97    1.495    0.742    0.371      28M     COMP
                                              BY       BY       BY       BY       BY       BY
                                            2.97    1.495    0.742    0.371      28M        0

SCREEN ANALYSIS, PERCENT-
   FEED....................................  3.37    12.39    21.22    21.35    37.13     4.54   100.00
   CRUSHED COAL............................  0.00     1.95    26.91    24.99    39.88     6.26   100.00

ASH, PERCCENT
   FEED.................................... 11.86    12.70    13.54    13.34    16.80    23.29    15.11
   CRUSHED COAL............................  0.00    13.61    13.45    13.33    16.57    20.59    15.11

PYRITIC SULFUR, PERCENT
   FEED....................................  2.69     2.79     2.61     2.34     2.46     2.99     2.54
   CRUSHED COAL............................  0.00     2.78     2.64     2.40     2.48     2.93     2.54

TOTAL SULFUR, PERCENT
   FEED....................................  3.58     4.28     3.86     3.61     3.61     4.15     3.77
   CRUSHED COAL............................  0.00     4.24     3.90     3.69     3.65     4.15     3.77

BTU/LB, MOISTURE FREE
   FEED.................................... 13,367   13,011   13,065   13,112   12,545   11,450   12,812
   CRUSHED COAL............................      0   13,028   13,078   13,108   12,582   11,892   12,812
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(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 8

SPECIFIC GRAVITY ANALYSIS OF FLOWSTREAM NUMBER 2 (DRY BASIS)

ORIGIN - UNIT NUMBER 1 DESTINATION - UNIT NUMBER 2

| SIZE FRACTION AND WEIGHT | SPECIFIC GRAVITY | WEIGHT | DIRECT, PERCENT ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB | WEIGHT | CUMULATIVE, PERCENT ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.97 BY 1.495<br>PERCENT OF FLOW 8.0 | FLOAT-1.30 | 9.20 | 4.15 | 0.66 | 2.14 | 14.690 | 9.20 | 4.15 | 0.66 | 2.14 | 14.690 |
| | 1.30-1.35 | 58.39 | 6.02 | 1.50 | 3.04 | 14.341 | 67.60 | 5.76 | 1.47 | 2.92 | 14.389 |
| | 1.35-1.40 | 8.68 | 11.44 | 3.42 | 4.90 | 13.354 | 76.36 | 6.41 | 1.69 | 3.14 | 14.271 |
| | 1.40-1.50 | 9.81 | 20.10 | 3.90 | 5.38 | 11.890 | 86.17 | 7.97 | 1.94 | 3.40 | 14.000 |
| | 1.50-1.60 | 3.92 | 27.00 | 4.11 | 5.50 | 10.625 | 90.09 | 8.84 | 2.04 | 3.47 | 13.853 |
| | 1.60-1.90 | 3.89 | 41.20 | 4.80 | 6.29 | 8.383 | 93.99 | 10.10 | 2.15 | 3.61 | 13.627 |
| | 1.90-2.20 | 1.93 | 62.32 | 8.50 | 9.98 | 4.723 | 95.92 | 11.23 | 2.28 | 3.74 | 13.448 |
| | 2.20-2.50 | 2.52 | 71.63 | 9.55 | 11.33 | 3.104 | 98.43 | 12.78 | 2.47 | 3.92 | 13.183 |
| | 2.50-2.80 | 0.88 | 69.72 | 11.93 | 13.41 | 3.335 | 99.31 | 13.20 | 2.55 | 4.01 | 13.096 |
| | 2.80-SINK | 0.69 | 61.04 | 36.35 | 37.95 | 3.292 | 100.00 | 13.61 | 2.70 | 4.24 | 13.020 |
| 1.495 BY 0.742<br>PERCENT OF FLOW 26.9 | FLOAT-1.30 | 13.06 | 3.97 | 0.65 | 2.00 | 14.730 | 13.06 | 3.97 | 0.65 | 2.00 | 14.730 |
| | 1.30-1.35 | 54.88 | 6.17 | 1.50 | 2.84 | 14.320 | 67.95 | 5.75 | 1.34 | 2.68 | 14.465 |
| | 1.35-1.40 | 9.53 | 11.00 | 3.10 | 4.47 | 13.453 | 77.48 | 6.40 | 1.56 | 2.90 | 14.260 |
| | 1.40-1.50 | 8.78 | 19.21 | 3.93 | 5.15 | 12.070 | 86.26 | 7.70 | 1.80 | 3.13 | 14.062 |
| | 1.50-1.60 | 4.01 | 27.62 | 4.08 | 5.09 | 10.660 | 90.27 | 8.59 | 1.90 | 3.22 | 13.911 |
| | 1.60-1.90 | 3.76 | 41.95 | 4.49 | 5.37 | 8.325 | 94.03 | 9.93 | 2.01 | 3.36 | 13.688 |
| | 1.90-2.20 | 2.57 | 65.09 | 8.33 | 8.85 | 4.352 | 96.60 | 11.48 | 2.17 | 3.45 | 13.439 |
| | 2.20-2.50 | 1.61 | 74.67 | 9.36 | 10.83 | 2.713 | 98.21 | 12.44 | 2.29 | 3.56 | 13.283 |
| | 2.50-2.80 | 1.02 | 74.68 | 11.43 | 12.04 | 2.619 | 99.24 | 13.08 | 2.39 | 3.64 | 13.153 |
| | 2.80-SINK | 0.76 | 61.34 | 35.43 | 37.65 | 3.243 | 100.00 | 13.45 | 2.64 | 3.90 | 13.078 |
| 0.742 BY 0.371<br>PERCENT OF FLOW 25.2 | FLOAT-1.30 | 20.42 | 4.05 | 0.69 | 2.12 | 14.710 | 20.42 | 4.05 | 0.69 | 2.12 | 14.710 |
| | 1.30-1.35 | 48.48 | 6.18 | 1.42 | 2.70 | 14.336 | 68.90 | 5.55 | 1.21 | 2.53 | 14.447 |
| | 1.35-1.40 | 9.03 | 10.79 | 3.30 | 4.31 | 13.496 | 77.93 | 6.15 | 1.41 | 2.73 | 14.337 |
| | 1.40-1.50 | 8.43 | 18.19 | 4.30 | 5.50 | 12.214 | 86.37 | 7.33 | 1.67 | 3.00 | 14.129 |
| | 1.50-1.60 | 3.74 | 27.26 | 4.42 | 5.73 | 10.713 | 90.11 | 8.16 | 1.78 | 3.12 | 13.987 |
| | 1.60-1.90 | 3.85 | 41.74 | 5.79 | 6.72 | 8.291 | 93.96 | 9.53 | 1.95 | 3.27 | 13.754 |
| | 1.90-2.20 | 2.43 | 67.27 | 6.42 | 6.88 | 4.093 | 96.39 | 10.99 | 2.06 | 3.36 | 13.510 |
| | 2.20-2.50 | 1.78 | 77.84 | 7.56 | 8.49 | 2.268 | 98.16 | 12.20 | 2.16 | 3.45 | 13.307 |
| | 2.50-2.80 | 1.31 | 79.19 | 7.99 | 8.59 | 2.041 | 99.48 | 13.08 | 2.24 | 3.52 | 13.158 |
| | 2.80-SINK | 0.52 | 61.40 | 33.74 | 36.07 | 3.507 | 100.00 | 13.33 | 2.40 | 3.69 | 13.108 |
| 0.371 BY 28M<br>PERCENT OF FLOW 39.9 | FLOAT-1.30 | 23.06 | 3.14 | 0.55 | 1.85 | 14.878 | 23.06 | 3.14 | 0.55 | 1.85 | 14.878 |
| | 1.30-1.35 | 40.30 | 5.92 | 1.32 | 2.59 | 14.386 | 63.36 | 4.90 | 1.04 | 2.32 | 14.565 |
| | 1.35-1.40 | 10.37 | 9.93 | 2.03 | 4.14 | 13.646 | 73.73 | 5.61 | 1.29 | 2.58 | 14.435 |
| | 1.40-1.50 | 7.29 | 16.36 | 4.15 | 5.21 | 12.543 | 81.02 | 6.58 | 1.55 | 2.81 | 14.265 |
| | 1.50-1.60 | 3.16 | 25.31 | 5.18 | 6.00 | 10.971 | 84.18 | 7.28 | 1.69 | 2.96 | 14.142 |
| | 1.60-1.90 | 6.11 | 48.16 | 6.00 | 6.79 | 7.235 | 90.29 | 10.05 | 1.98 | 3.22 | 13.674 |
| | 1.90-2.20 | 2.75 | 65.13 | 5.47 | 6.08 | 4.480 | 93.04 | 11.68 | 2.08 | 3.31 | 13.402 |
| | 2.20-2.50 | 3.88 | 82.38 | 5.44 | 5.74 | 1.666 | 96.92 | 14.51 | 2.22 | 3.40 | 12.932 |
| | 2.50-2.80 | 2.38 | 86.36 | 4.81 | 4.98 | 1.053 | 99.30 | 16.23 | 2.28 | 3.44 | 12.647 |
| | 2.80-SINK | 0.70 | 63.99 | 31.46 | 33.38 | 3.261 | 100.00 | 16.57 | 2.48 | 3.65 | 12.582 |

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 9

SPECIFIC GRAVITY ANALYSIS OF FLOWSTREAM NUMBER 2 (CONTINUED)

ORIGIN - UNIT NUMBER 1 DESTINATION - UNIT NUMBER 2

| SIZE FRACTION AND WEIGHT | SPECIFIC GRAVITY | DIRECT, PERCENT WEIGHT | DIRECT, PERCENT ASH | DIRECT, PERCENT PYRITIC SULFUR | DIRECT, PERCENT TOTAL SULFUR | DIRECT, PERCENT BTU/LB | CUMULATIVE, PERCENT WEIGHT | CUMULATIVE, PERCENT ASH | CUMULATIVE, PERCENT PYRITIC SULFUR | CUMULATIVE, PERCENT TOTAL SULFUR | CUMULATIVE, PERCENT BTU/LB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 28M BY 0<br>PERCENT OF FLOW 6.3 | FLOAT-1.30 | 26.66 | 3.11 | 0.62 | 1.93 | 14,878 | 26.66 | 3.11 | 0.62 | 1.93 | 14,878 |
| | 1.30-1.35 | 31.13 | 6.22 | 1.48 | 2.87 | 14,315 | 57.79 | 4.78 | 1.04 | 2.44 | 14,575 |
| | 1.35-1.40 | 8.11 | 9.87 | 2.59 | 3.98 | 13,660 | 65.90 | 5.41 | 1.23 | 2.63 | 14,462 |
| | 1.40-1.50 | 7.54 | 16.28 | 3.39 | 4.98 | 12,555 | 73.44 | 6.53 | 1.45 | 2.86 | 14,266 |
| | 1.50-1.60 | 4.27 | 23.45 | 4.51 | 5.59 | 11,354 | 77.71 | 7.46 | 1.62 | 3.01 | 14,106 |
| | 1.60-1.90 | 5.87 | 39.26 | 5.74 | 6.80 | 8,896 | 83.59 | 9.61 | 1.93 | 3.28 | 13,743 |
| | 1.90-2.20 | 3.31 | 59.55 | 6.70 | 7.50 | 5,331 | 86.90 | 11.51 | 2.12 | 3.44 | 13,419 |
| | 2.20-2.50 | 4.70 | 77.88 | 5.04 | 5.49 | 2,415 | 91.60 | 14.92 | 2.27 | 3.54 | 12,855 |
| | 2.50-2.80 | 6.33 | 86.96 | 3.79 | 4.30 | 977 | 97.93 | 19.57 | 2.36 | 3.59 | 12,687 |
| | 2.80-SINK | 2.07 | 58.73 | 29.68 | 30.50 | 2,650 | 100.00 | 20.59 | 2.93 | 4.15 | 11,892 |
| COMPOSITE<br>PERCENT OF FEED 100.0 | FLOAT-1.30 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 | 19.67 | 3.53 | 0.61 | 1.96 | 14,806 |
| | 1.30-1.35 | 46.05 | 6.08 | 1.42 | 2.72 | 14,350 | 65.72 | 5.32 | 1.18 | 2.49 | 14,486 |
| | 1.35-1.40 | 9.64 | 10.44 | 2.96 | 4.27 | 13,555 | 75.35 | 5.97 | 1.40 | 2.72 | 14,367 |
| | 1.40-1.50 | 8.04 | 17.76 | 3.39 | 5.25 | 12,303 | 83.39 | 7.11 | 1.65 | 2.96 | 14,168 |
| | 1.50-1.60 | 3.62 | 25.48 | 4.56 | 5.90 | 10,833 | 87.01 | 7.92 | 1.77 | 3.03 | 14,030 |
| | 1.60-1.90 | 4.86 | 44.72 | 5.62 | 6.47 | 7,015 | 91.87 | 9.06 | 1.98 | 3.27 | 13,701 |
| | 1.90-2.20 | 2.64 | 65.14 | 6.59 | 7.16 | 4,420 | 94.50 | 11.48 | 2.11 | 3.37 | 13,442 |
| | 2.20-2.50 | 2.77 | 79.78 | 6.47 | 6.92 | 2,032 | 97.27 | 13.35 | 2.23 | 3.48 | 13,117 |
| | 2.50-2.80 | 1.97 | 93.51 | 6.12 | 6.50 | 1,441 | 99.24 | 14.74 | 2.31 | 3.54 | 12,866 |
| | 2.80-SINK | 0.76 | 63.59 | 32.91 | 34.59 | 3,195 | 100.00 | 15.11 | 2.54 | 3.77 | 12,812 |

(Continued)

TABLE A-7. (Continued)

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                                                                                      PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 10
SUMMARY OF THE PERFORMANCE CHARACTERISTICS OF UNIT NUMBER  2
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                                                    PREJET SCREEN
                                              SIZE OF OPENING = 0.37 INCHES

SIZE, INCHES OR MESH                          2.97     1.495     0.742     0.371       28M      COMP
                                                BY        BY        BY        BY        BY
                                             1.495     0.742     0.371       28M         0

SCREEN ANALYSIS, PERCENT-
   FEED.....................................  1.95     26.91     24.99     39.88      6.26    100.00
   OVERFLOW (COARSE) STREAM.................  3.62     49.97     46.41      0.00      0.00    100.00
   UNDERFLOW (FINE) STREAM..................  0.00      0.00      0.00     86.43     13.57    100.00

ASH, PERCCENT
   FEED..................................... 13.61     13.45     13.33     16.57     20.59     15.11
   OVERFLOW (COARSE) STREAM................. 13.61     13.45     13.33      0.00      0.00     13.40
   UNDERFLOW (FINE) STREAM..................  0.00      0.00      0.00     16.57     20.59     17.11

PYRITIC SULFUR, PERCENT
   FEED.....................................  2.78      2.64      2.40      2.48      2.93      2.54
   OVERFLOW (COARSE) STREAM.................  2.78      2.64      2.40      0.00      0.00      2.54
   UNDERFLOW (FINE) STREAM..................  0.00      0.00      0.00      2.48      2.93      2.54

TOTAL SULFUR, PERCENT
   FEED.....................................  4.24      3.90      3.69      3.65      4.15      3.77
   OVERFLOW (COARSE) STREAM.................  4.24      3.90      3.69      0.00      0.00      3.82
   UNDERFLOW (FINE) STREAM..................  0.00      0.00      0.00      3.65      4.15      3.72

BTU/LB, MOISTURE FREE
   FEED..................................... 13,028    13,078    13,108    12,582    11,892    12,812
   OVERFLOW (COARSE) STREAM................. 13,028    13,078    13,108         0         0    13,090
   UNDERFLOW (FINE) STREAM..................      0         0         0    12,562    11,892    12,488

WEIGHT RATIO, UNDERFLOW TO FEED.... PERCENT    0.0       0.0       0.0     100.0     100.0      46.1
BTU RATIO, UNDERFLOW TO FEED.......     DO     0.0       0.0       0.0     100.0     100.0      45.0
UNDERSIZE MATERIAL IN OVERFLOW STREAM. DO      0.0       0.0       0.0       0.0       0.0       0.0
OVERSIZE MATERIAL IN UNDERFLOW STREAM. DO      0.0       0.0       0.0       0.0       0.0       0.0
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(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 11

SPECIFIC GRAVITY ANALYSIS OF FLOWSTREAM NUMBER 3 (DRY BASIS)

ORIGIN - UNIT NUMBER 2 U DESTINATION - UNIT NUMBER 3

| SIZE FRACTION AND WEIGHT | SPECIFIC GRAVITY | DIRECT, PERCENT | | | | | CUMULATIVE, PERCENT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WEIGHT | ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB | WEIGHT | ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB |
| 2.97 BY 1.495 | FLOAT-1.30 | 9.28 | 4.15 | 0.66 | 2.14 | 14,690 | 9.28 | 4.15 | 0.66 | 2.14 | 14,690 |
| PERCENT OF FLOW 3.6 | 1.30-1.35 | 58.39 | 6.02 | 1.60 | 3.04 | 14,341 | 67.68 | 5.76 | 1.47 | 2.92 | 14,389 |
| | 1.35-1.40 | 8.68 | 11.44 | 3.42 | 4.90 | 13,354 | 76.36 | 6.41 | 1.69 | 3.14 | 14,271 |
| | 1.40-1.50 | 9.81 | 20.18 | 3.90 | 5.38 | 11,890 | 86.17 | 7.97 | 1.94 | 3.40 | 14,006 |
| | 1.50-1.60 | 3.92 | 27.80 | 4.11 | 5.58 | 10,625 | 90.09 | 8.84 | 2.04 | 3.49 | 13,853 |
| | 1.60-1.90 | 3.89 | 41.20 | 4.80 | 6.29 | 8,383 | 93.99 | 10.18 | 2.15 | 3.61 | 13,627 |
| | 1.90-2.20 | 1.93 | 52.32 | 8.50 | 9.98 | 4,723 | 95.92 | 11.23 | 2.28 | 3.74 | 13,446 |
| | 2.20-2.50 | 2.52 | 71.83 | 9.55 | 11.03 | 3,104 | 98.43 | 12.78 | 2.47 | 3.92 | 13,183 |
| | 2.50-2.80 | 0.88 | 69.72 | 11.93 | 13.41 | 3,335 | 99.31 | 13.28 | 2.55 | 4.01 | 13,096 |
| | 2.80-SINK | 0.69 | 61.04 | 36.55 | 37.95 | 3,292 | 100.00 | 13.61 | 2.78 | 4.24 | 13,028 |
| 1.495 BY 0.742 | FLOAT-1.30 | 13.06 | 3.97 | 0.65 | 2.00 | 14,730 | 13.06 | 3.97 | 0.65 | 2.00 | 14,730 |
| PERCENT OF FLOW 50.0 | 1.30-1.35 | 54.88 | 6.17 | 1.50 | 2.84 | 14,328 | 67.95 | 5.75 | 1.34 | 2.68 | 14,405 |
| | 1.35-1.40 | 9.53 | 11.00 | 3.18 | 4.47 | 13,453 | 77.48 | 6.40 | 1.56 | 2.90 | 14,288 |
| | 1.40-1.50 | 8.78 | 19.21 | 3.93 | 5.15 | 12,070 | 86.26 | 7.70 | 1.80 | 3.13 | 14,062 |
| | 1.50-1.60 | 4.01 | 27.82 | 4.00 | 5.09 | 10,660 | 90.27 | 8.59 | 1.90 | 3.22 | 13,911 |
| | 1.60-1.90 | 3.76 | 41.95 | 4.49 | 5.37 | 8,325 | 94.03 | 9.93 | 2.01 | 3.30 | 13,688 |
| | 1.90-2.20 | 2.57 | 65.09 | 8.33 | 8.85 | 4,352 | 96.60 | 11.40 | 2.17 | 3.45 | 13,439 |
| | 2.20-2.50 | 1.61 | 74.67 | 9.36 | 10.03 | 2,713 | 98.21 | 12.44 | 2.29 | 3.56 | 13,263 |
| | 2.50-2.80 | 1.02 | 74.68 | 11.43 | 12.04 | 2,614 | 99.24 | 13.08 | 2.39 | 3.64 | 13,153 |
| | 2.80-SINK | 0.76 | 61.34 | 35.83 | 37.65 | 3,243 | 100.00 | 13.45 | 2.64 | 3.90 | 13,078 |
| 0.742 BY 0.371 | FLOAT-1.30 | 20.42 | 4.05 | 0.69 | 2.12 | 14,710 | 20.42 | 4.05 | 0.69 | 2.12 | 14,710 |
| PERCENT OF FLOW 46.4 | 1.30-1.35 | 48.48 | 6.18 | 1.42 | 2.70 | 14,336 | 68.90 | 5.55 | 1.21 | 2.53 | 14,447 |
| | 1.35-1.40 | 9.03 | 10.78 | 3.00 | 4.31 | 13,496 | 77.93 | 6.15 | 1.41 | 2.73 | 14,337 |
| | 1.40-1.50 | 8.43 | 18.18 | 4.00 | 5.50 | 12,214 | 86.37 | 7.33 | 1.67 | 3.00 | 14,129 |
| | 1.50-1.60 | 3.74 | 27.26 | 4.42 | 5.73 | 10,713 | 90.11 | 8.16 | 1.78 | 3.12 | 13,987 |
| | 1.60-1.90 | 3.85 | 41.74 | 5.79 | 6.72 | 8,291 | 93.96 | 9.53 | 1.95 | 3.27 | 13,754 |
| | 1.90-2.20 | 2.43 | 67.27 | 6.42 | 6.88 | 4,093 | 96.39 | 10.99 | 2.06 | 3.36 | 13,510 |
| | 2.20-2.50 | 1.78 | 77.84 | 7.86 | 8.49 | 2,268 | 98.16 | 12.20 | 2.16 | 3.45 | 13,307 |
| | 2.50-2.80 | 1.31 | 79.19 | 7.99 | 8.59 | 2,041 | 99.48 | 13.08 | 2.24 | 3.52 | 13,158 |
| | 2.80-SINK | 0.52 | 61.40 | 33.74 | 36.07 | 3,507 | 100.00 | 13.33 | 2.40 | 3.69 | 13,108 |
| COMPOSITE | FLOAT-1.30 | 16.34 | 4.02 | 0.67 | 2.07 | 14,718 | 16.34 | 4.02 | 0.67 | 2.07 | 14,718 |
| PERCENT OF FEED 53.9 | 1.30-1.35 | 52.04 | 6.17 | 1.47 | 2.79 | 14,332 | 68.38 | 5.66 | 1.28 | 2.62 | 14,424 |
| | 1.35-1.40 | 9.27 | 10.92 | 3.11 | 4.41 | 13,469 | 77.65 | 6.28 | 1.50 | 2.83 | 14,310 |
| | 1.40-1.50 | 8.66 | 18.78 | 3.96 | 5.32 | 12,128 | 86.31 | 7.54 | 1.75 | 3.08 | 14,091 |
| | 1.50-1.60 | 3.88 | 27.57 | 4.19 | 5.39 | 10,682 | 90.19 | 8.40 | 1.85 | 3.18 | 13,945 |
| | 1.60-1.90 | 3.81 | 41.82 | 5.11 | 6.04 | 8,311 | 93.99 | 9.75 | 1.98 | 3.30 | 13,716 |
| | 1.90-2.20 | 2.48 | 66.00 | 7.47 | 7.99 | 4,245 | 96.48 | 11.20 | 2.12 | 3.42 | 13,473 |
| | 2.20-2.50 | 1.72 | 76.04 | 8.65 | 9.34 | 2,521 | 98.20 | 12.34 | 2.24 | 3.52 | 13,281 |
| | 2.50-2.80 | 1.15 | 76.93 | 9.62 | 10.25 | 2,331 | 99.35 | 13.09 | 2.32 | 3.60 | 13,154 |
| | 2.80-SINK | 0.65 | 61.35 | 35.07 | 37.07 | 3,344 | 100.00 | 13.46 | 2.54 | 3.82 | 13,050 |

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 12

SPECIFIC GRAVITY ANALYSIS OF FLOWSTREAM NUMBER 4 (DRY BASIS)

ORIGIN - UNIT NUMBER 2 L DESTINATION - UNIT NUMBER 6

| SIZE FRACTION AND WEIGHT | SPECIFIC GRAVITY | DIRECT, PERCENT WEIGHT | ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB | CUMULATIVE, PERCENT WEIGHT | ASH | PYRITIC SULFUR | TOTAL SULFUR | BTU/LB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.371 BY 28M<br>PERCENT OF FLOW 86.4 | FLOAT-1.30 | 23.06 | 3.14 | 0.55 | 1.85 | 14,878 | 23.06 | 3.14 | 0.55 | 1.85 | 14,878 |
| | 1.30-1.35 | 40.30 | 5.91 | 1.32 | 2.59 | 14,386 | 63.36 | 4.90 | 1.04 | 2.32 | 14,565 |
| | 1.35-1.40 | 10.37 | 9.93 | 2.53 | 4.14 | 13,646 | 73.73 | 5.61 | 1.29 | 2.58 | 14,435 |
| | 1.40-1.50 | 7.29 | 16.36 | 4.15 | 5.21 | 12,543 | 81.02 | 6.58 | 1.55 | 2.81 | 14,265 |
| | 1.50-1.60 | 3.16 | 25.31 | 5.18 | 6.80 | 10,971 | 84.18 | 7.28 | 1.69 | 2.96 | 14,142 |
| | 1.60-1.90 | 6.11 | 44.16 | 6.00 | 6.79 | 7,235 | 90.29 | 10.05 | 1.99 | 3.22 | 13,674 |
| | 1.90-2.20 | 2.75 | 55.13 | 5.47 | 6.08 | 4,480 | 93.04 | 11.68 | 2.08 | 3.31 | 13,402 |
| | 2.20-2.50 | 3.88 | 82.38 | 5.44 | 5.74 | 1,666 | 96.92 | 14.51 | 2.22 | 3.40 | 12,932 |
| | 2.50-2.80 | 2.38 | 86.36 | 4.81 | 4.98 | 1,053 | 99.30 | 16.23 | 2.28 | 3.44 | 12,647 |
| | 2.80-SINK | 0.70 | 63.99 | 31.46 | 33.36 | 3,261 | 100.00 | 16.57 | 2.48 | 3.65 | 12,582 |
| 28M BY 0<br>PERCENT OF FLOW 13.6 | FLOAT-1.30 | 26.66 | 3.11 | 0.62 | 1.93 | 14,878 | 26.66 | 3.11 | 0.62 | 1.93 | 14,878 |
| | 1.30-1.35 | 31.13 | 6.22 | 1.40 | 2.87 | 14,315 | 57.79 | 4.78 | 1.04 | 2.44 | 14,575 |
| | 1.35-1.40 | 8.11 | 9.87 | 2.59 | 3.98 | 13,660 | 65.90 | 5.41 | 1.23 | 2.63 | 14,462 |
| | 1.40-1.50 | 7.54 | 16.28 | 3.39 | 4.98 | 12,555 | 73.44 | 6.53 | 1.45 | 2.86 | 14,266 |
| | 1.50-1.60 | 4.28 | 23.45 | 4.51 | 5.59 | 11,354 | 77.71 | 7.46 | 1.62 | 3.01 | 14,106 |
| | 1.60-1.90 | 5.87 | 38.06 | 5.34 | 6.80 | 8,896 | 83.59 | 9.61 | 1.93 | 3.28 | 13,743 |
| | 1.90-2.20 | 3.31 | [illegible] | 6.90 | 7.50 | 5,331 | 86.90 | 11.51 | 2.12 | 3.44 | 13,419 |
| | 2.20-2.50 | 4.70 | 77.68 | 5.04 | 5.49 | 2,415 | 91.60 | 14.92 | 2.27 | 3.54 | 12,855 |
| | 2.50-2.80 | 6.33 | 86.96 | 3.79 | 4.30 | 977 | 97.93 | 19.57 | 2.36 | 3.59 | 12,087 |
| | 2.80-SINK | 2.07 | 58.73 | 29.60 | 30.50 | 2,650 | 100.00 | 20.59 | 2.93 | 4.15 | 11,892 |
| COMPOSITE<br>PERCENT OF FEED 46.1 | FLOAT-1.30 | 23.55 | 3.14 | 0.56 | 1.86 | 14,878 | 23.55 | 3.14 | 0.56 | 1.86 | 14,878 |
| | 1.30-1.35 | 39.05 | 5.95 | 1.33 | 2.62 | 14,378 | 62.60 | 4.69 | 1.04 | 2.33 | 14,566 |
| | 1.35-1.40 | 10.06 | 9.93 | 2.80 | 4.12 | 13,647 | 72.67 | 5.59 | 1.29 | 2.58 | 14,439 |
| | 1.40-1.50 | 7.32 | 16.35 | 4.04 | 5.16 | 12,545 | 79.99 | 6.57 | 1.54 | 2.82 | 14,265 |
| | 1.50-1.60 | 3.31 | 24.98 | 5.36 | 6.59 | 11,038 | 83.30 | 7.30 | 1.68 | 2.97 | 14,137 |
| | 1.60-1.90 | 6.08 | 46.84 | 5.99 | 6.79 | 7,452 | 89.38 | 9.99 | 1.97 | 3.23 | 13,682 |
| | 1.90-2.20 | 2.82 | 64.24 | 5.70 | 6.30 | 4,615 | 92.20 | 11.65 | 2.09 | 3.32 | 13,405 |
| | 2.20-2.50 | 3.99 | 81.66 | 5.37 | 5.70 | 1,786 | 96.20 | 14.56 | 2.22 | 3.42 | 12,922 |
| | 2.50-2.80 | 2.92 | 86.54 | 4.51 | 4.78 | 1,031 | 99.12 | 16.68 | 2.29 | 3.46 | 12,572 |
| | 2.80-SINK | 0.88 | 65.49 | 30.87 | 32.46 | 3,067 | 100.00 | 17.11 | 2.54 | 3.72 | 12,488 |

(Continued)

## TABLE A-7. (Continued)

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                                                                PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.50 SPG PAGE 13
SUMMARY OF THE PERFORMANCE CHARACTERISTICS OF UNIT NUMBER  3
------- -- --- ----------- --------------- -- ---- ------  -

                                                 DENSE MEDIUM VESSEL
                                          SPECIFIC GRAVITY OF SEPARATION =1.60

SIZE, INCHES OR MESH                           2.97     1.495     0.742     0.371       28M      COMP
                                                 BY        BY        BY        BY        BY
                                              1.495     0.742     0.371       28M         0

SCREEN ANALYSIS, PERCENT-
   FEED....................................    3.62     49.97     46.41      0.00      0.00    100.00
   CLEAN COAL..............................    3.62     50.01     46.37      0.00      0.00    100.00
   REFUSE..................................    3.66     49.65     46.69      0.00      0.00    100.00

ASH, PERCCENT
   FEED....................................   13.61     13.45     13.33      0.00      0.00     13.40
   CLEAN COAL..............................    8.77      8.52      8.09      0.00      0.00      8.33
   REFUSE..................................   55.88     57.22     59.30      0.00      0.00     58.14

PYRITIC SULFUR, PERCENT
   FEED....................................    2.78      2.64      2.40      0.00      0.00      2.54
   CLEAN COAL..............................    2.03      1.89      1.77      0.00      0.00      1.84
   REFUSE..................................    9.37      9.30      7.95      0.00      0.00      8.67

TOTAL SULFUR, PERCENT
   FEED....................................    4.24      3.90      3.69      0.00      0.00      3.82
   CLEAN COAL..............................    3.49      3.21      3.11      0.00      0.00      3.17
   REFUSE..................................   10.65     10.18      8.77      0.00      0.00      9.51

BTU/LB, MOISTURE FREE
   FEED.................................... 13,028    13,078    13,108         0         0    13,090
   CLEAN COAL.............................. 13,865    13,923    13,998         0         0    13,956
   REFUSE..................................  5,723     5,558     5,300         0         0     5,444
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(Continued)

## TABLE A-7. (Continued)

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                                                                  1   PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 14
SUMMARY OF THE PERFORMANCE CHARACTERISTICS OF UNIT NUMBER  3 (CONTINUED)
------- -- --- ----------- --------------- -- ---- ------  - -----------

                                                    DENSE MEDIUM VESSEL
                                               SPECIFIC GRAVITY OF SEPARATION =1.60

SIZE, INCHES OR MESH
                                                  2.97      1.495     0.742     0.371       28M      COMP
                                                    BY        BY        BY        BY        BY
                                                 1.495     0.742     0.371      28M         0
ACTUAL RECOVERY..................... PERCENT      89.7      89.9      89.8       0.0       0.0
THEORETICAL RECOVERY..............      DO        85.6      99.0      99.9       0.0       0.0      89.6
RECOVERY EFFICIENCY...............      DO        99.9      99.9      99.9       0.0       0.0      89.9
BTU RECOVERY......................      DO        95.5      95.7      95.9       0.0       0.0      99.9
ASH ERROR.........................      DO         0.0       0.0       0.0       0.0       0.0      55.8
FLOAT IN REFUSE......... PERCENT OF PRODUCT        9.1       9.1       9.8       0.0       0.0       0.0
SINK IN CLEAN COAL......        DO                 0.1       0.1       0.1       0.0       0.0       9.0
TOTAL MISPLACED MATERIAL... PERCENT OF FEED        1.0       1.0       1.0       0.0       0.0       0.0
NEAR GRAVITY 0.1 MATERIAL..     DO                 4.2       4.2       4.0       0.0       0.0       1.0
SPECIFIC GRAVITY OF SEPARATION.............       1.64      1.64      1.64      0.00      0.00       4.1
PROBABLE ERROR, SPECIFIC GRAVITY...........      0.317     0.317     0.317     0.000     0.000      1.64
IMPERFECTION...............................      0.194     0.194     0.194     0.000     0.000     0.317
ERROR AREA.................................         19        19        19         0         0     0.194
DISTRIBUTION, PERCENT TO WASHED COAL                                                                  19
  (SPECIFIC GRAVITY FRACTION)-
   FLOAT-1.30..............................
   1.30-1.35...............................                                                        100.0
   1.35-1.40...............................                                                        100.0
   1.40-1.50...............................                                                        100.0
   1.50-1.60...............................                                                         99.8
   1.60-1.90...............................                                                         89.6
   1.90-2.20...............................                                                          1.4
   2.20-2.50...............................                                                          0.0
   2.50-2.80...............................                                                          0.0
   2.80-SINK...............................                                                          0.0
                                                                                                     0.0
```

(Continued)

## TABLE A-7. (Continued)

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                                                          PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 38

                                    *** OUTPUT ***

SUMMARY DATA FOR UNITS
------- ---- --- -----

UNIT NUMBER      UNIT TYPE                               DECISION VARIABLES         YIELD       BTU RECOVERY
-----------      ---------                                                        (PERCENT)      (PERCENT)
                                                         ------------------       ---------    -----------
     1        14 (CRUSHER (OVERSIZE))                           2.970
     2        23 (PREWET SCREEN)                                0.371
     3         2 (DENSE MEDIUM VESSEL)                          1.600              89.8           95.6
     4        41 (BLENDER (3 X 3/8 CLEAN COAL))                 2.250
     5        41 (BLENDER (3 X 3/8 REFUSE))                     6.000
     6        23 (SCREEN (FINES))                               0.023
     7         3 (DENSE MEDIUM CYCLONE)                         1.600              83.8           94.2
     8        41 (BLENDER (3/8 X 28 M CLEAN COAL))              5.250
     9        41 (BLENDER (3/8 X 28 M REFUSE))                  5.250
    10         7 (FROTH FLOTATION CELLS)                                           74.4           68.3
    11        41 (BLENDER (28M X 0 CLEAN COAL))                25.000
    12        41 (BLENDER (28M X 0 REFUSE))                    25.000
    13        41 (BLENDER (CLEAN COAL))
    14        41 (BLENDER (REFUSE))
```

(Continued)

TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 39

SUMMARY DATA FOR FLOWSTREAMS

| FLOWSTREAM NUMBER | ORIGIN UNIT NO. | DESTINATION UNIT NO. | DRY BASIS | | | | | | FLOWRATE TPH MOIST | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | FLOWRATE TPH | ASH (PERCENT) | PYRITIC SULFUR (PERCENT) | TOTAL SULFUR (PERCENT) | BTU/LB | LBS SO2/ MILLION BTU | INCL IN- TERNAL H2O | TOTAL INCL ALL H2O |
| 1 | 0 | 1 | 380.2 | 15.11 | 2.54 | 3.77 | 12,812 | 5.89 | 390.2 | 393.5 |
| 2 | 1 | 2 | 380.2 | 15.11 | 2.54 | 3.77 | 12,812 | 5.89 | 390.2 | **N.A.** |
| 3 | 2 U | 3 | 204.8 | 13.40 | 2.54 | 3.82 | 13,090 | 5.83 | 210.3 | **N.A.** |
| 4 | 2 L | 6 | 175.4 | 17.11 | 2.54 | 3.72 | 12,488 | 5.95 | 179.9 | **N.A.** |
| 5 | 3 C | 4 | 183.9 | 8.33 | 1.84 | 3.17 | 13,956 | 4.55 | 189.2 | **N.A.** |
| 6 | 3 R | 5 | 20.8 | 58.14 | 8.67 | 9.51 | 5,444 | 34.92 | 21.1 | **N.A.** |
| 7 | 6 U | 7 | 151.6 | 16.57 | 2.48 | 3.65 | 12,582 | 5.80 | 155.5 | **N.A.** |
| 8 | 6 L | 10 | 23.8 | 20.59 | 2.93 | 4.15 | 11,892 | 6.98 | 24.4 | **N.A.** |
| 9 | 7 C | 8 | 127.0 | 7.21 | 1.67 | 2.94 | 14,155 | 4.16 | 130.7 | **N.A.** |
| 10 | 7 R | 9 | 24.6 | 64.81 | 6.67 | 7.29 | 4,473 | 32.60 | 24.9 | **N.A.** |
| 11 | 10 C | 11 | 17.7 | 7.33 | 1.57 | 2.95 | 14,130 | 4.18 | 18.2 | **N.A.** |
| 12 | 10 R | 12 | 6.1 | 59.03 | 6.88 | 7.62 | 5,404 | 28.20 | 6.2 | **N.A.** |
| 13 | 4 C | 13 | 183.9 | 8.33 | 1.84 | 3.17 | 13,956 | 4.55 | 189.2 | 193.6 |
| 14 | 8 C | 13 | 127.0 | 7.21 | 1.67 | 2.94 | 14,155 | 4.16 | 130.7 | 137.9 |
| 15 | 11 C | 13 | 17.7 | 7.33 | 1.57 | 2.95 | 14,130 | 4.18 | 18.2 | 24.3 |
| 16 | 5 R | 14 | 20.8 | 58.14 | 8.67 | 9.51 | 5,444 | 34.92 | 21.1 | 22.4 |
| 17 | 9 R | 14 | 24.6 | 64.81 | 6.67 | 7.29 | 4,473 | 32.60 | 24.9 | 26.2 |
| 18 | 12 R | 14 | 6.1 | 59.03 | 6.88 | 7.62 | 5,404 | 28.20 | 6.2 | 8.2 |
| 19 | 13 C | 0 | 328.6 | 7.84 | 1.76 | 3.07 | 14,042 | 4.37 | 338.1 | 356.3 |
| 20 | 14 R | 0 | 51.6 | 61.43 | 7.50 | 8.22 | 4,975 | 33.06 | 52.1 | 56.9 |

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 40

ULTIMATE ANALYSES OF RAW COAL, CLEAN COAL, AND REFUSE

| COMPONENT | RAW COAL WEIGHT % | CLEAN COAL WEIGHT % | REFUSE WEIGHT % |
|---|---|---|---|
| CARBON | 65.35 | 67.89 | 22.69 |
| HYDROGEN | 4.42 | 4.59 | 1.53 |
| OXYGEN | 7.87 | 8.18 | 2.73 |
| NITROGEN | 1.35 | 1.40 | 0.47 |
| WATER (INTERNAL) | 2.57 | 2.67 | 0.89 |
| SUBTOTAL PURE COAL COMPONENTS | 81.57 | 84.73 | 28.32 |
| ASH | 13.81 | 7.23 | 55.72 |
| SULFUR (ORGANIC) | 1.52 | 1.21 | 0.65 |
| SULFUR (PYRITIC) | 2.15 | 1.62 | 6.81 |
| SUBTOTAL ASH PLUS SULFUR | 17.48 | 10.07 | 63.18 |
| CHLORINE | 0.10 | 0.10 | 0.10 |
| WATER (SURFACE) | 0.85 | 5.10 | 8.40 |
| SUBTOTAL CHLORINE PLUS SURFACE MOISTURE | 0.95 | 5.20 | 8.50 |
| TOTAL (WEIGHT PERCENT) | 100.00 | 100.00 | 100.00 |
| BTU/LB, MOIST BASIS | 12121 | 12951 | 4513 |
| BTU/LB, DRY BASIS | 12812 | 14042 | 4975 |
| LB SO2/M BTU | 6.05 | 4.37 | 33.03 |
| WEIGHT RECOVERY, MOIST BASIS (%) | | 90.53 | |
| WEIGHT RECOVERY, DRY BASIS (%) | | 86.46 | |
| BTU RECOVERY (%) | | 94.76 | |

(Continued)

## TABLE A-7. (Continued)

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PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 41

TOTAL CAPITAL INVESTMENT
----- ------- ----------


                                                   INVESTMENT, 1982 K$
DIRECT INVESTMENT                                  -------------------
-----------------

RAW COAL STORAGE                                          3,452
RAW COAL SIZING                                           1,070
COARSE COAL CLEANING                                      1,507
INTERMEDIATE COAL CLEANING                                1,341
FINE COAL CLEANING                                        2,028
REFUSE DISPOSAL                                           1,836
CLEAN COAL STORAGE                                        3,290
                                                       --------
     TOTAL PROCESS CAPITAL                               14,524

SERVICES, UTILITIES, AND MISCELLANEOUS                      871
                                                       --------
     TOTAL DIRECT INVESTMENT                             15,395

INDIRECT INVESTMENT
-------------------

ENGINEERING DESIGN AND SUPERVISION                          770
ARCHITECT AND ENGINEERING CONTRACTOR                        308
CONSTRUCTION EXPENSE                                      2,463
CONTRACTOR FEES                                             770
                                                       --------
     TOTAL INDIRECT INVESTMENT                            4,311

CONTINGENCY                                               1,971
                                                       --------
     TOTAL FIXED INVESTMENT                              21,677

OTHER CAPITAL INVESTMENT
------------------------

ALLOWANCE FOR STARTUP AND MODIFICATIONS                   1,734
INTEREST DURING CONSTRUCTION                              3,382
LAND                                                        584
WORKING CAPITAL                                           1,075
                                                       --------
     TOTAL CAPITAL INVESTMENT                            28,452
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(Continued)

TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG PAGE 42

| ANNUAL REVENUE REQUIREMENT | ANNUAL QUANTITY | UNIT COST, $ | TOTAL ANNUAL COST, 1984 K$ |
|---|---|---|---|
| DIRECT COSTS | | | |
| CONVERSION COSTS | | | |
| OPERATING LABOR AND SUPERVISION | 112,840 MAN-HR | 15.00/MAN-HR | 1,693 |
| UTILITIES | | | |
| PROCESS WATER | 26,000 KGAL | 0.14/KGAL | 4 |
| ELECTRICITY | 6,898,000 KWH | 0.037/KWH | 255 |
| DIESEL FUEL | 76,000 GAL | 1.60/GAL | 122 |
| PROCESS MATERIAL | | | |
| MAGNETITE | 1,260 TON | 107.35/TON | 135 |
| MAINTENANCE | | | |
| LABOR AND MATERIAL | | | 924 |
| ANALYSIS | 3,698 MAN-HR | 21.00/MAN-HR | 78 |
| TOTAL CONVERSION COSTS | | | 3,211 |
| TOTAL DIRECT COSTS | | | 3,211 |
| INDIRECT COSTS | | | |
| OVERHEADS | | | |
| PLANT AND ADMINISTRATIVE | | | 1,698 |
| TOTAL FIRST-YEAR OPERATING AND MAINTENANCE COSTS | | | 4,909 |
| LEVELIZED CAPITAL CHARGES (14.7% OF TOTAL CAPITAL INVESTMENT) | | | 4,182 |
| TOTAL FIRST-YEAR ANNUAL REVENUE REQUIREMENTS | | | 9,091 |
| LEVELIZED FIRST-YEAR OPERATING AND MAINTENANCE COSTS (1.886 FIRST-YEAR O AND M) | | | 9,258 |
| LEVELIZED CAPITAL CHARGES (14.7% OF TOTAL CAPITAL INVESTMENT) | | | 4,182 |
| LEVELIZED ANNUAL REVENUE REQUIREMENTS | | | 13,440 |

(Continued)

## TABLE A-7. (Continued)

```
PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG                CASE 001

                    *** INPUTS ***

RAW COAL CHARACTERISTICS
--- ---- ---------------

RAW COAL ANALYSIS, WT % :

  C      H      O      N      S      CL    ASH    H2O
65.35  4.42   7.87   1.35   3.67   0.10  13.81   3.42

HEATING VALUE OF RAW COAL = 12121. BTU/LB (MOIST BASIS)

PARTIAL SCRUBBING DESIGN

BOILER CHARACTERISTICS
------ ---------------

MEGAWATTS =  1000.

BOILER HEAT RATE =  9200. BTU/KWH

EXCESS AIR =  39. PERCENT, INCLUDING LEAKAGE

HOT GAS TEMPERATURE = 300. DEG F

COAL ANALYSIS, WT % AS FIRED :

  C      H      O      N      S      CL    ASH    H2O
65.35  4.42   7.87   1.35   3.67   0.10  13.81   3.42

SULFUR OVERHEAD =  92.0 PERCENT

ASH OVERHEAD =  80.0 PERCENT

HEATING VALUE OF COAL = 12121. BTU/LB (AS FIRED)

EMISSION STANDARD
-------- --------

SIP:  1.20 LBS SO2/M BTU TO THE BOILER
```

(Continued)

TABLE A-7.  (Continued)

```
ALKALI
------

LIMESTONE :

       CACO3        =  95.00 WT % DRY BASIS
       SOLUBLE MGO =   0.15
       INERTS       =   4.85
       MOISTURE CONTENT =   5.00 LB H2O/100 LBS DRY LIMESTONE
       LIMESTONE HARDNESS WORK INDEX FACTOR = 10.00
       LIMESTONE DEGREE OF GRIND FACTOR =  5.70

FLY ASH :

       SOLUBLE CAO =   0.0  WT %
       SOLUBLE MGO =   0.0
       INERTS       = 100.00


RAW MATERIAL HANDLING AREA
--- -------- -------- ----

NUMBER OF REDUNDANT ALKALI PREPARATION UNITS =    1



SCRUBBER SYSTEM VARIABLES
-------- ------ ---------

SO2 REMOVAL = 88.0 % OF SO2 TO THE SCRUBBER, IN BYPASS CASES

NUMBER OF OPERATING SCRUBBING TRAINS =   8

NUMBER OF REDUNDANT SCRUBBING TRAINS =   2

SPRAY TOWER LIQUID-TO-GAS RATIO =  90. GAL/1000 ACF(SATD)

SPRAY TOWER GAS VELOCITY = 10.0 FT/SEC

INDUCED DRAFT SCRUBBER FAN OPTION

SCRUBBER PRESSURE = 14.7 PSIA

STOICHIOMETRY =  1.30 MOLE CACO3 ADDED AS LIMESTONE
                      PER MOLE (SO2+2HCL) ABSORBED

SO2 EMISSION LIMIT = 1.20 LB SO2/M BTU

ENTRAINMENT LEVEL = 0.10 WT %

EFFLUENT HOLD TANK RESIDENCE TIME =  10.0 MIN

SO2 OXIDIZED IN SYSTEM =  30.0 PERCENT

SOLIDS IN RECIRCULATED SLURRY =  15.0 WT %
```

(Continued)

TABLE A-7. (Continued)

```
SOLIDS DISPOSAL SYSTEM
------ -------- ------

COST OF LAND =  5000.00 DOLLARS/ACRE

SOLIDS IN SYSTEM SLUDGE DISCHARGE =  40.0 WT %

MAXIMUM POND AREA =  9999. ACRES

MAXIMUM EXCAVATION =  25.00 FT

DISTANCE TO POND =  5280. FT

POND LINED WITH 12.0 INCHES CLAY


STEAM REHEATER (IN-LINE)
----- -------- ---------

HEAT OF VAPORIZATION OF SATURATED STEAM =  752. BTU/LB

STACK FLUE GAS TEMPERATURE = 175. DEG F

SUPERFICIAL GAS VELOCITY (FACE VELOCITY) =  25.0 FT/SEC


WATER BALANCE INPUTS
----- ------- ------

RAINFALL(IN/YEAR)                       35.

POND SEEPAGE(CM/SEC)*10**6              50.

POND EVAPORATION(IN/YEAR)               32.


ECONOMIC PREMISES
-------- --------

1981  TVA-EPA ECONOMIC PREMISES

PROJECTED REVENUE REQUIREMENTS INCLUDE LEVELIZED OPERATING AND MAINTENANCE COSTS
RATE =  1.886 TIMES FIRST YEAR OPERATING AND MAINTENANCE COSTS

FREIGHT INCLUDED IN DIRECT INVESTMENT
FREIGHT RATE =  3.5 % OF EQUIPMENT COST

SALES TAX INCLUDED IN DIRECT INVESTMENT
SALES TAX RATE =  4.0 % OF EQUIPMENT COST

LABOR OVERTIME INCLUDED IN DIRECT INVESTMENT
OVERTIME RATE =  1.5

PROCESS MAINTENANCE =  7.0 % OF DIRECT PROCESS INVESTMENT

POND MAINTENANCE =  3.0 % OF DIRECT POND INVESTMENT
```

(Continued)

## TABLE A-7. (Continued)

```
PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG                CASE 001

                *** OUTPUTS ***

EMERGENCY BY-PASS
--------- -------

EMERGENCY BY-PASS DESIGNED FOR   95.0 %

HOT GAS FROM BOILER
--- --- ---- ------

         MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2         12.074        0.4130E+05     0.1813E+07
HCL          0.006        0.2141E+02     0.7805E+03
SO2          0.234        0.7994E+03     0.5121E+05
O2           5.535        0.1893E+05     0.6059E+06
N2          74.900        0.2562E+06     0.7179E+07
H2O          7.251        0.2480E+05     0.4469E+06

FLYASH EMISSION =  9.115 LBS/MILLION BTU TO BOILER
                =  83056. LB/HR

HOT GAS FLOW RATE =  .2161E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .3158E+07 ACFM (300. DEG F, 14.7 PSIA)

CORRESPONDING COAL FIRING RATE =  .7590E+06 LB/HR

HOT GAS HUMIDITY =  0.046 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 126. DEG F


HOT GAS TO BY-PASS
--- --- -- -------

         MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2         12.074        0.4819E+04     0.2121E+06
HCL          0.006        0.2498E+01     0.9107E+02
SO2          0.234        0.9326E+02     0.5974E+04
O2           5.535        0.2209E+04     0.7069E+05
N2          74.900        0.2989E+05     0.8375E+06
H2O          7.251        0.2894E+04     0.5213E+05

HOT GAS BY-PASSED 11.67 %
```

(Continued)

## TABLE A-7. (Continued)

```
FLYASH EMISSION =  0.021 LBS/MILLION BTU TO BOILER
                =    192. LB/HR

HOT GAS FLOW RATE =  .2521E+06 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .3684E+06 ACFM (300. DEG F, 14.7 PSIA)

HOT GAS TO SCRUBBER
--- --- -- --------

          MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2          12.074        0.3648E+05     0.1606E+07
HCL           0.006        0.1891E+02     0.6896E+03
SO2           0.234        0.7061E+03     0.4523E+05
O2            5.535        0.1673E+05     0.5352E+06
N2           74.900        0.2263E+06     0.6342E+07
H2O           7.251        0.2191E+05     0.3947E+06

SO2 CONCENTRATION IN SCRUBRER INLET GAS = 2337. PPM
                                        = 5.57 LBS / MILLION BTU TO BOILER

FLYASH EMISSION =  0.158 LBS/MILLION BTU TO BOILER
                =   1456. LB/HR

        SOLUBLE CAO IN FLY ASH =     0. LB/HR
        SOLUBLE MGO IN FLY ASH =     0.

HOT GAS FLOW RATE =  .1909E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .2790E+07 ACFM (300. DEG F, 14.7 PSIA)

MW EQUIVALENT OF SCRUBBER =  883 MEGAWATTS

CORRESPONDING COAL FIRING RATE =  .6705E+06 LB/HR

HOT GAS HUMIDITY =  0.046 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 126. DEG F


WET GAS FROM SCRUBBER
--- --- ---- --------

          MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2          11.490        0.3713E+05     0.1634E+07
HCL           0.000        0.9456E+00     0.3448E+02
SO2           0.024        0.7908E+02     0.5065E+04
O2            5.147        0.1663E+05     0.5322E+06
N2           70.035        0.2263E+06     0.6342E+07
H2O          13.304        0.4299E+05     0.7746E+06
```

(Continued)

## TABLE A-7. (Continued)

```
SO2 CONCENTRATION IN SCRUBBER OUTLET GAS =  245. PPM

FLYASH EMISSION =  0.079 LBS/MILLION BTU TO BOILER
                =    728. LB/HR

TOTAL WATER PICKUP =  779.  GPM
           INCLUDING   19.6 GPM ENTRAINMENT

WET GAS FLOW RATE =  .2041E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .2299E+07 ACFM (126. DEG F, 14.7 PSIA)

WET GAS SATURATION HUMIDITY =  0.091 LB H2O/LB DRY GAS


FLUE GAS TO STACK
---- --- -- -----

        MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2        11.538        0.4195E+05     0.1846E+07
HCL         0.001        0.3443E+01     0.1255E+03
SO2         0.047        0.1723E+03     0.1104E+05
O2          5.182        0.1884E+05     0.6029E+06
N2         70.469        0.2562E+06     0.7179E+07
H2O        12.763        0.4640E+05     0.8360E+06
CALCULATED SO2 REMOVAL EFFICIENCY IN THE SCRUBBER (WITH BYPASS IF APPLICABLE) =  78.5 %

SPECIFIED  SO2 EMISSION =   1.20 POUNDS PER MILLION BTU TO THE BOILER

CALCULATED SO2 CONCENTRATION IN STACK GAS =     474. PPM

CALCULATED HCL CONCENTRATION IN STACK GAS =       9. PPM


FLYASH EMISSION =  0.100 LBS/MILLION BTU TO BOILER
                =    920. LB/HR

STACK GAS FLOW RATE =  .2297E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                    =  .2605E+07 ACFM (175. DEG F, 14.7 PSIA)
```

(Continued)

## TABLE A-7. (Continued)

PROJECTED CAPITAL INVESTMENT - PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG CASE 001
LIMESTONE SLURRY PROCESS -- BASIS: 883 MW SCRUBBING UNIT - 1000 MW GENERATING UNIT, 1984 STARTUP

| | INVESTMENT, THOUSANDS OF 1982 DOLLARS | | | | DISTRIBUTION |
|---|---|---|---|---|---|
| | RAW MATERIAL PREPARATION | SCRUBBING | WASTE DISPOSAL | TOTAL | DOLLARS PER KW |
| EQUIPMENT | | | | | |
| MATERIAL | 3440. | 24242. | 93. | 27775. | 27.78 |
| LABOR | 343. | 3067. | 32. | 3442. | 3.44 |
| PIPING | | | | | |
| MATERIAL | 566. | 9571. | 1282. | 11419. | 11.42 |
| LABOR | 252. | 2004. | 406. | 2662. | 2.66 |
| DUCTWORK | | | | | |
| MATERIAL | 0. | 5251. | 0. | 5251. | 5.25 |
| LABOR | 0. | 4675. | 0. | 4675. | 4.68 |
| FOUNDATIONS | | | | | |
| MATERIAL | 403. | 308. | 20. | 731. | 0.73 |
| LABOR | 1063. | 671. | 42. | 1776. | 1.78 |
| STRUCTURAL | | | | | |
| MATERIAL | 231. | 687. | 2. | 921. | 0.92 |
| LABOR | 150. | 1198. | 4. | 1352. | 1.35 |
| ELECTRICAL | | | | | |
| MATERIAL | 286. | 1490. | 149. | 1925. | 1.92 |
| LABOR | 892. | 2640. | 323. | 3855. | 3.86 |
| INSTRUMENTATION | | | | | |
| MATERIAL | 198. | 1533. | 13. | 1744. | 1.74 |
| LABOR | 30. | 254. | 9. | 294. | 0.29 |
| BUILDINGS | | | | | |
| MATERIAL | 191. | 0. | 0. | 191. | 0.19 |
| LABOR | 211. | 0. | 0. | 211. | 0.21 |
| SALES TAX ( 4.0 %) AND FREIGHT ( 3.5 %) | 399. | 3231. | 117. | 3747. | 3.75 |
| TOTAL PROCESS CAPITAL | 8654. | 60824. | 2494. | 71972. | 71.97 |
| SERVICES AND MISCELLANEOUS ( 6.0 %) | 519. | 3649. | 150. | 4318. | 4.32 |
| TOTAL DIRECT PROCESS INVESTMENT | 9173. | 64474. | 2643. | 76290. | 76.29 |
| POND CONSTRUCTION MATERIAL | 0. | 0. | 376. | 376. | 0.38 |
| POND CONSTRUCTION LABOR | 0. | 0. | 22722. | 22722. | 22.72 |
| POND SALES TAX ( 4.0 %) AND FREIGHT ( 3.5 %) | 0. | 0. | 28. | 28. | 0.03 |
| TOTAL DIRECT POND INVESTMENT | 0. | 0. | 23126. | 23126. | 23.13 |
| TOTAL DIRECT INVESTMENT | 9173. | 64474. | 25769. | 99416. | 99.42 |
| ENGINEERING DESIGN AND SUPERVISION ( 6.0 %) | 550. | 3868. | 159. | 4577. | 4.58 |
| ARCHITECT AND ENGINEERING CONTRACTOR ( 1.0 %) | 92. | 645. | 26. | 763. | 0.76 |
| CONSTRUCTION EXPENSES (14.0 %) | 1284. | 9026. | 370. | 10681. | 10.68 |
| CONTRACTOR FEES ( 4.0 %) | 367. | 2579. | 106. | 3052. | 3.05 |
| CONTINGENCY (10.0 %) | 1147. | 8059. | 330. | 9536. | 9.54 |
| POND INDIRECTS ( 2.0, 1.0, 8.0, 5.0, 10.0 %) | 0. | 0. | 6383. | 6383. | 6.38 |
| SUBTOTAL FIXED INVESTMENT | 12613. | 88651. | 33143. | 134408. | 134.41 |
| STARTUP & MODIFICATION ALLOWANCE ( 8.0, 0.8 %) | 1009. | 7092. | 291. | 8392. | 8.39 |
| INTEREST DURING CONSTRUCTION (15.6 %) | 1968. | 13830. | 5170. | 20968. | 20.97 |
| ROYALTIES ( 0.0 %) | 0. | 0. | 0. | 0. | 0.0 |
| LAND | 11. | 7. | 2965. | 2983. | 2.98 |
| WORKING CAPITAL | 466. | 3275. | 1309. | 5051. | 5.05 |
| TOTAL CAPITAL INVESTMENT | 16067. | 112855. | 42879. | 171801. | 171.80 |

(Continued)

## TABLE A-7. (Continued)

```
PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG                 CASE 002

                 *** INPUTS ***

RAW COAL CHARACTERISTICS
--- ---- ---------------

RAW COAL ANALYSIS, WT % :

  C       H       O       N       S      CL     ASH    H2O
65.35   4.42    7.87    1.35    3.67    0.10   13.81   3.42

HEATING VALUE OF RAW COAL = 12121. BTU/LB (MOIST BASIS)

PARTIAL SCRUBBING DESIGN

BOILER CHARACTERISTICS
------ ---------------

MEGAWATTS =  1000.

BOILER HEAT RATE =  9230. BTU/KWH

EXCESS AIR =  39. PERCENT, INCLUDING LEAKAGE

HOT GAS TEMPERATURE = 300. DEG F

CLEAN COAL ANALYSIS, WT % AS FIRED :

  C       H       O       N       S      CL     ASH    H2O
67.89   4.59    8.18    1.40    2.83    0.10    7.23   7.77

SULFUR OVERHEAD =  92.0 PERCENT

ASH OVERHEAD =  80.0 PERCENT

HEATING VALUE OF COAL = 12951. BTU/LB (AS FIRED)

EMISSION STANDARD
-------- --------

SIP:  1.20 LBS SO2/M BTU TO THE BOILER
```

(Continued)

## TABLE A-7. (Continued)

```
ALKALI
------

LIMESTONE :

        CACO3        =  95.00 WT % DRY BASIS
        SOLUBLE MGO =   0.15
        INERTS       =   4.85
        MOISTURE CONTENT =   5.00 LB H2O/100 LBS DRY LIMESTONE
        LIMESTONE HARDNESS WORK INDEX FACTOR = 10.00
        LIMESTONE DEGREE OF GRIND FACTOR =  5.70

FLY ASH :

        SOLUBLE CAO =   0.0  WT %
        SOLUBLE MGO =   0.0
        INERTS       = 100.00


RAW MATERIAL HANDLING AREA
--- -------- -------- ----

NUMBER OF REDUNDANT ALKALI PREPARATION UNITS =    1


SCRUBBER SYSTEM VARIABLES
-------- ------ ---------

SO2 REMOVAL = 88.8 % OF SO2 TO THE SCRUBBER, IN BYPASS CASES

NUMBER OF OPERATING SCRUBBING TRAINS =   8

NUMBER OF REDUNDANT SCRUBBING TRAINS =   2

SPRAY TOWER LIQUID-TO-GAS RATIO =  90. GAL/1000 ACF(SATD)

SPRAY TOWER GAS VELOCITY = 10.0 FT/SEC

INDUCED DRAFT SCRUBBER FAN OPTION

SCRUBBER PRESSURE = 14.7 PSIA

STOICHIOMETRY =  1.30 MOLE CACO3 ADDED AS LIMESTONE
                      PER MOLE (SO2+2HCL) ABSORBED

SO2 EMISSION LIMIT = 1.20 LB SO2/M BTU

ENTRAINMENT LEVEL = 0.10 WT %

EFFLUENT HOLD TANK RESIDENCE TIME =  10.0 MIN

SO2 OXIDIZED IN SYSTEM =  30.0 PERCENT

SOLIDS IN RECIRCULATED SLURRY =  15.0 WT %
```

(Continued)

## TABLE A-7. (Continued)

```
SOLIDS DISPOSAL SYSTEM
------ -------- ------

COST OF LAND =  5000.00 DOLLARS/ACRE

SOLIDS IN SYSTEM SLUDGE DISCHARGE =  40.0 WT %

MAXIMUM POND AREA =  9999. ACRES

MAXIMUM EXCAVATION =  25.00 FT

DISTANCE TO POND =  5280. FT

POND LINED WITH 12.0 INCHES CLAY


STEAM REHEATER (IN-LINE)
----- -------- ---------

HEAT OF VAPORIZATION OF SATURATED STEAM =  752. BTU/LB

STACK FLUE GAS TEMPERATURE = 175. DEG F

SUPERFICIAL GAS VELOCITY (FACE VELOCITY) =  25.0 FT/SEC


WATER BALANCE INPUTS
----- ------- ------

RAINFALL(IN/YEAR)                       35.

POND SEEPAGE(CM/SEC)*10**8              50.

POND EVAPORATION(IN/YEAR)               32.


ECONOMIC PREMISES
-------- --------

1981  TVA-EPA ECONOMIC PREMISES

PROJECTED REVENUE REQUIREMENTS INCLUDE LEVELIZED OPERATING AND MAINTENANCE COSTS
RATE =  1.886 TIMES FIRST YEAR OPERATING AND MAINTENANCE COSTS

FREIGHT INCLUDED IN DIRECT INVESTMENT
FREIGHT RATE =  3.5 % OF EQUIPMENT COST

SALES TAX INCLUDED IN DIRECT INVESTMENT
SALES TAX RATE =  4.0 % OF EQUIPMENT COST

LABOR OVERTIME INCLUDED IN DIRECT INVESTMENT
OVERTIME RATE =  1.5

PROCESS MAINTENANCE =  7.0 % OF DIRECT PROCESS INVESTMENT

POND MAINTENANCE =  3.0 % OF DIRECT POND INVESTMENT
```

(Continued)

## TABLE A-7. (Continued)

```
PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG                    CASE 002

                    *** OUTPUTS ***

EMERGENCY BY-PASS
--------- -------

EMERGENCY BY-PASS DESIGNED FOR   60.5 %

HOT GAS FROM BOILER
--- --- ---- ------

        MOLE PERCENT     LB-MOLE/HR      LB/HR

CO2        12.063        0.4028E+05      0.1773E+07
HCL         0.006        0.2010E+02      0.7330E+03
SO2         0.173        0.5793E+03      0.3711E+05
O2          5.507        0.1839E+05      0.5885E+06
N2         74.515        0.2488E+06      0.6973E+07
H2O         7.736        0.2583E+05      0.4654E+06

FLYASH EMISSION =  4.468 LBS/MILLION BTU TO BOILER
                =  41242. LB/HR

HOT GAS FLOW RATE =  .2109E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .3083E+07 ACFM (300. DEG F, 14.7 PSIA)

CORRESPONDING COAL FIRING RATE =  .7127E+06 LB/HR

HOT GAS HUMIDITY =  0.050 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 127. DEG F


HOT GAS TO BY-PASS
--- --- -- -------

        MOLE PERCENT     LB-MOLE/HR      LB/HR

CO2        12.063        0.8457E+04      0.3722E+06
HCL         0.006        0.4221E+01      0.1539E+03
SO2         0.173        0.1216E+03      0.7792E+04
O2          5.507        0.3861E+04      0.1235E+06
N2         74.515        0.5224E+05      0.1464E+07
H2O         7.736        0.5423E+04      0.9771E+05

HOT GAS BY-PASSED 20.99 %
```

(Continued)

## TABLE A-7. (Continued)

```
FLYASH EMISSION =  0.035 LBS/MILLION BTU TO BOILER
                =    320. LB/HR

HOT GAS FLOW RATE =  .4429E+06 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .6473E+06 ACFM (300. DEG F, 14.7 PSIA)

HOT GAS TO SCRUBBER
--- --- -- --------

         MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2         12.063        0.3183E+05     0.1401E+07
HCL          0.006        0.1588E+02     0.5791E+03
SO2          0.173        0.4577E+03     0.2932E+05
O2           5.507        0.1453E+05     0.4649E+06
N2          74.515        0.1966E+06     0.5509E+07
H2O          7.736        0.2041E+05     0.3677E+06

SO2 CONCENTRATION IN SCRUBBER INLET GAS = 1735. PPM
                                        = 4.02 LBS / MILLION BTU TO BOILER

FLYASH EMISSION =  0.131 LBS/MILLION BTU TO BOILER
                =   1205. LB/HR

        SOLUBLE CAO IN FLY ASH =     0. LB/HR
        SOLUBLE MGO IN FLY ASH =     0.

HOT GAS FLOW RATE =  .1667E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .2436E+07 ACFM (300. DEG F, 14.7 PSIA)

MW EQUIVALENT OF SCRUBBER =  790 MEGAWATTS

CORRESPONDING COAL FIRING RATE =  .5630E+06 LB/HR

HOT GAS HUMIDITY =  0.050 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 127. DEG F


WET GAS FROM SCRUBBER
--- --- ---- --------

         MOLE PERCENT     LB-MOLE/HR     LB/HR

CO2         11.432        0.3225E+05     0.1419E+07
HCL          0.000        0.7941E+00     0.2895E+02
SO2          0.018        0.5126E+02     0.3284E+04
O2           5.129        0.1447E+05     0.4630E+06
N2          69.692        0.1966E+06     0.5509E+07
H2O         13.729        0.3873E+05     0.6978E+06
```

(Continued)

## TABLE A-7. (Continued)

```
SO2 CONCENTRATION IN SCRUBBER OUTLET GAS =  182. PPM

FLYASH EMISSION =  0.065 LBS/MILLION BTU TO BOILER
                =    603. LB/HR

TOTAL WATER PICKUP =  677.  GPM
          INCLUDING   16.2 GPM ENTRAINMENT

WET GAS FLOW RATE =  .1782E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                  =  .2011E+07 ACFM (127. DEG F, 14.7 PSIA)

WET GAS SATURATION HUMIDITY =  0.094 LB H2O/LB DRY GAS


FLUE GAS TO STACK
---- --- -- -----

        MOLE PERCENT      LB-MOLE/HR       LB/HR

CO2        11.543         0.4071E+05      0.1791E+07
HCL         0.001         0.5015E+01      0.1828E+03
SO2         0.049         0.1729E+03      0.1108E+05
O2          5.197         0.1833E+05      0.5865E+06
N2         70.562         0.2488E+06      0.6973E+07
H2O        12.647         0.4460E+05      0.8035E+06

CALCULATED SO2 REMOVAL EFFICIENCY IN THE SCRUBBER (WITH BYPASS IF APPLICABLE) =  70.2 %

SPECIFIED  SO2 EMISSION =   1.20 POUNDS PER MILLION BTU TO THE BOILER

CALCULATED SO2 CONCENTRATION IN STACK GAS =     490. PPM

CALCULATED HCL CONCENTRATION IN STACK GAS =      14. PPM


FLYASH EMISSION =  0.100 LBS/MILLION BTU TO BOILER
                =    923. LB/HR

STACK GAS FLOW RATE =  .2228E+07 SCFM ( 60. DEG F, 14.7 PSIA)
                    =  .2720E+07 ACFM (175. DEG F, 14.7 PSIA)
```

(Continued)

## TABLE A-7. (Continued)

PROJECTED CAPITAL INVESTMENT - PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG CASE 002
LIMESTONE SLURRY PROCESS -- BASIS: 790 MW SCRUBBING UNIT - 1000 MW GENERATING UNIT, 1984 STARTUP

| | INVESTMENT, THOUSANDS OF 1982 DOLLARS | | | | DISTRIBUTION |
|---|---|---|---|---|---|
| | RAW MATERIAL PREPARATION | SCRUBBING | WASTE DISPOSAL | TOTAL | DOLLARS PER KW |
| EQUIPMENT | | | | | |
| MATERIAL | 3076. | 20833. | 82. | 23992. | 23.99 |
| LABOR | 314. | 2731. | 29. | 3074. | 3.07 |
| PIPING | | | | | |
| MATERIAL | 481. | 8196. | 1080. | 9758. | 9.76 |
| LABOR | 222. | 1631. | 357. | 2210. | 2.21 |
| DUCTWORK | | | | | |
| MATERIAL | 0. | 6774. | 0. | 6774. | 6.77 |
| LABOR | 0. | 4259. | 0. | 4259. | 4.26 |
| FOUNDATIONS | | | | | |
| MATERIAL | 342. | 285. | 20. | 647. | 0.65 |
| LABOR | 885. | 622. | 41. | 1548. | 1.55 |
| STRUCTURAL | | | | | |
| MATERIAL | 196. | 650. | 2. | 848. | 0.85 |
| LABOR | 142. | 1133. | 3. | 1278. | 1.28 |
| ELECTRICAL | | | | | |
| MATERIAL | 262. | 1277. | 146. | 1685. | 1.69 |
| LABOR | 760. | 2303. | 319. | 3382. | 3.38 |
| INSTRUMENTATION | | | | | |
| MATERIAL | 198. | 1515. | 13. | 1726. | 1.73 |
| LABOR | 30. | 254. | 9. | 294. | 0.29 |
| BUILDINGS | | | | | |
| MATERIAL | 148. | 0. | 0. | 148. | 0.15 |
| LABOR | 164. | 0. | 0. | 164. | 0.16 |
| SALES TAX ( 4.0 %) AND FREIGHT ( 3.5 %) | 353. | 2965. | 101. | 3418. | 3.42 |
| TOTAL PROCESS CAPITAL | 7575. | 55429. | 2201. | 65206. | 65.21 |
| SERVICES AND MISCELLANEOUS ( 6.0 %) | 455. | 3326. | 132. | 3912. | 3.91 |
| TOTAL DIRECT PROCESS INVESTMENT | 8030. | 58755. | 2333. | 69118. | 69.12 |
| POND CONSTRUCTION MATERIAL | 0. | 0. | 307. | 307. | 0.31 |
| POND CONSTRUCTION LABOR | 0. | 0. | 16282. | 16282. | 16.28 |
| POND SALES TAX ( 4.0 %) AND FREIGHT ( 3.5 %) | 0. | 0. | 23. | 23. | 0.02 |
| TOTAL DIRECT POND INVESTMENT | 0. | 0. | 16612. | 16612. | 16.61 |
| TOTAL DIRECT INVESTMENT | 8030. | 58755. | 18946. | 85730. | 85.73 |
| ENGINEERING DESIGN AND SUPERVISION ( 6.0 %) | 482. | 3525. | 140. | 4147. | 4.15 |
| ARCHITECT AND ENGINEERING CONTRACTOR ( 1.0 %) | 80. | 588. | 23. | 691. | 0.69 |
| CONSTRUCTION EXPENSES (14.0 %) | 1124. | 8226. | 327. | 9677. | 9.68 |
| CONTRACTOR FEES ( 4.0 %) | 321. | 2350. | 93. | 2765. | 2.76 |
| CONTINGENCY (10.0 %) | 1004. | 7344. | 292. | 8640. | 8.64 |
| POND INDIRECTS ( 2.0, 1.0, 8.0, 5.0, 10.0 %) | 0. | 0. | 4585. | 4585. | 4.58 |
| SUBTOTAL FIXED INVESTMENT | 11041. | 80788. | 24406. | 116234. | 116.23 |
| STARTUP & MODIFICATION ALLOWANCE ( 8.0, 0.0 %) | 883. | 6463. | 257. | 7603. | 7.60 |
| INTEREST DURING CONSTRUCTION (15.6 %) | 1722. | 12603. | 3807. | 18133. | 18.13 |
| ROYALTIES ( 0.0 %) | 0. | 0. | 0. | 0. | 0.0 |
| LAND | 10. | 6. | 2125. | 2142. | 2.14 |
| WORKING CAPITAL | 400. | 2928. | 944. | 4272. | 4.27 |
| TOTAL CAPITAL INVESTMENT | 14057. | 102787. | 31539. | 148383. | 148.38 |

(Continued)

# TABLE A-7. (Continued)

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PROJECTED ANNUAL REVENUE REQUIREMENTS - ACC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG                CASE 301
--------- ------ ------- ------------
LIMESTONE SLURRY PROCESS -- BASIS:  643 MW SCRUBBING UNIT - 1300 MW GENERATING UNIT, 1984 STARTUP

                               DISPLAY SHEET FOR YEAR=    1
                               ANNUAL OPERATION =  5500 HOURS

                    56.46 TONS PER HOUR                              DRY             SLUDGE
                          TOTAL CAPITAL INVESTMENT =     171001 (1982 K$)                     TOTAL
                                                                                             ANNUAL
                                                ANNUAL QUANTITY        UNIT COST,$      COST, 1984 K$
                                                ---------------        -----------      -------------
   DIRECT COSTS
   ------------
     RAW MATERIAL
     ------------
       LIMESTONE                                  239.4 K TONS        8.50/TON             2335
                                                                                       ----------
          SUBTOTAL RAW MATERIAL                                                            2035

     CONVERSION COSTS
     ----------------
       OPERATING LABOR AND
         SUPERVISION                            39650.0 MAN-HR       15.00/MAN-HR           595
       UTILITIES
         STEAM                                 602430.0 K LB          2.50/K LB            1506
         PROCESS WATER                         421770.0 K GAL         0.14/K GAL             59
         ELECTRICITY                         75526100.0 KWH           0.037/KWH            2795
       MAINTENANCE
         LABOR AND MATERIAL                                                                6034
       ANALYSES                                  6570.0 HR           21.00/HR               138
                                                                                       ----------
          SUBTOTAL CONVERSION COSTS                                                       11127

          SUBTOTAL DIRECT COSTS                                                           13162

   INDIRECT COSTS
   --------------
     OVERHEADS
       PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)                4061
                                                                                       ----------
     FIRST YEAR OPERATING AND MAINTENANCE COSTS                                           17222
     LEVELIZED CAPITAL CHARGES( 14.70% OF TOTAL CAPITAL INVESTMENT)                       25255
                                                                                       ----------
        FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                            42477

        EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)      8.75

        EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW)          7.72
-----------------------------------------------------------------------------------------------------------------------
     LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)          32500
     LEVELIZED CAPITAL CHARGES( 14.70% OF TOTAL CAPITAL INVESTMENT)                       25255
                                                                                       ----------
        LEVELIZED ANNUAL REVENUE REQUIREMENTS                                             57755

        EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)       11.89

        EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW)          10.50
-----------------------------------------------------------------------------------------------------------------------
     HEAT RATE   9200. BTU/KWH     -     HEAT VALUE OF COAL     12121 BTU/LB     -     COAL RATE   2087300 TONS/YR
```

(Continued)

## TABLE A-7. (Continued)

```
PROJECTED ANNUAL REVENUE REQUIREMENTS - PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG                 CASE 062
--------- ------ ------- ------------
LIMESTONE SLURRY PROCESS -- BASIS:  798 MW SCRUBBING UNIT - 1000 MW GENERATING UNIT, 1984 STARTUP

                              DISPLAY SHEET FOR YEAR=    1
                              ANNUAL OPERATION =  5500 HOURS

                  36.70 TONS PER HOUR                        DRY             SLUDGE
                        TOTAL CAPITAL INVESTMENT =    148383 (1982 K$)          TOTAL
                                                                                ANNUAL
                                          ANNUAL QUANTITY        UNIT COST,$    COST, 1984 K$
                                          ---------------        -----------    -------------
     DIRECT COSTS
     ------------
       RAW MATERIAL
       ------------
         LIMESTONE                           155.8 K TONS         8.50/TON             1325
                                                                                 ----------
            SUBTOTAL RAW MATERIAL                                                      1325

       CONVERSION COSTS
       ----------------
         OPERATING LABOR AND
           SUPERVISION                     37720.0 MAN-HR       15.00/MAN-HR            566
         UTILITIES
           STEAM                          267960.0 K LB          2.50/K LB              678
           PROCESS WATER                  331820.0 K GAL         0.14/K GAL              47
           ELECTRICITY                  63034700.0 KWH           0.037/KWH             2332
         MAINTENANCE
           LABOR AND MATERIAL                                                          5337
         ANALYSES                           6590.0 HR           21.00/HR                138
                                                                                 ----------
            SUBTOTAL CONVERSION COSTS                                                  9889

            SUBTOTAL DIRECT COSTS                                                     10414

     INDIRECT COSTS
     --------------
       OVERHEADS
         PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)          3624
                                                                                 ----------
       FIRST YEAR OPERATING AND MAINTENANCE COSTS                                     14038
       LEVELIZED CAPITAL CHARGES( 14.70% OF TOTAL CAPITAL INVESTMENT)                 21812
                                                                                 ----------
          FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                      35851

          EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)    8.25

          EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW)        6.52
--------------------------------------------------------------------------------------------------------------------
       LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)    26500
       LEVELIZED CAPITAL CHARGES( 14.70% OF TOTAL CAPITAL INVESTMENT)                 21812
                                                                                 ----------
          LEVELIZED ANNUAL REVENUE REQUIREMENTS                                       48312

          EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)     11.12

          EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW)         8.78
--------------------------------------------------------------------------------------------------------------------
       HEAT RATE   9230. BTU/KWH     -     HEAT VALUE OF COAL     12950 BTU/LB     -     COAL RATE   1960000 TONS/YR
```

(Continued)

## TABLE A-7. (Continued)

```
                          TENNESSEE VALLEY AUTHORITY
                 COAL CLEANING ECONOMIC BENEFITS AND PENALTIES
                      COMPUTERIZED COST ESTIMATE PROGRAM
                        REVISION DATE NOVEMBER 4,1981


          PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG

                                    INPUTS

PLANT SIZE (MW)                              1000.0
PLANT ON-STREAM TIME (HR/YR)                 5500.0       EXCESS COMBUSTION AIR (%)                       39.0
SULFUR OVERHEAD (%)                            92.0       ASH OVERHEAD (%)                                80.0
TOTAL CAPITAL INVESTMENT YEAR                  1982       CHEMICAL ENGINEERING PLANT INDEX               297.9
ANNUAL REVENUE REQUIREMENT YEAR                1984       CHEMICAL ENGINEERING PLANT INDEX               342.6
ESP FLYASH EMISSION RATE (LB/M BTU)           0.200       ESP GAS PRESSURE (PSIA)                       14.700
TAXATION METHOD                                   1       TAX RATE ($/TON COAL SHIPPED)                  0.500
OUTPUT INDICATOR                                  0       DISTANCE TO COAL CLEANING PLANT (MILES)        200.0

        COAL CHARACTERISTIC                         RAW COAL          CLEAN COAL

COMPOSITION (WT%, AS RECEIVED)
      CARBON                                         65.35              67.89
      HYDROGEN                                        4.42               4.59
      OXYGEN                                          7.87               8.18
      NITROGEN                                        1.35               1.40
      SULFUR                                          3.67               2.83
      CHLORINE                                        0.10               0.10
      ASH                                            13.81               7.23
      WATER                                           3.42               7.77

HEATING VALUE (BTU/LB, AS RECEIVED)                12121.             12991.
BOILER HEAT RATE(BTU/KWH)                           9230.              9230.
PRICE OF COAL ($/TON)                               20.81              55.00
MAXIMUM CRUSHER FEED COAL SIZE (INCHES)              6.00               2.97
MAXIMUM PULVERIZER FEED COAL SIZE (INCHES)           0.75               0.75
```

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG

| AREA | TOTAL CAPITAL INVESTMENT BENEFIT, 1982 DOLLARS | ANNUAL REVENUE REQUIREMENT BENEFIT, 1984 DOLLARS/YR |
|---|---|---|
| COAL LOSS | 0. | -2374400. |
| FGD PROCESS | 23418000. | 6626000. |
| TRANSPORTATION | 0. | 749200. |
| UMW TRUST FUND | 0. | 265000. |
| COAL TAX | 0. | 63700. |
| ELECTROSTATIC PRECIPITATOR | -1614000. | -248200. |
| ASH HANDLING AND DISPOSAL | 8035000. | 2317000. |
| GRINDING | 1358000. | 291500. |
| MAINTENANCE | 0. | 1893000. |
| AVAILABILITY | 0. | 2513100. |
|  | ----------- | ----------- |
| TOTAL | 31196992. | 12095200. |

(Continued)

## TABLE A-7. (Continued)

PCC 1 (PITTSBURGH SEAM, JEFFERSON CO., OHIO ) 1.60 SPG

COMBINED TOTAL CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENTS

| COST ELEMENT | PHYSICAL COAL CLEANING | PCC COST BENEFITS | NET COST |
|---|---|---|---|
| TOTAL CAPITAL INVESTMENT (1982 K$) | 28452. | 31197. | -2745. |
| FIRST YEAR ANNUAL REVENUE REQUIREMENT (1984 K$/YR) | 9091. | 12095. | -3004. |
| LEVELIZED ANNUAL REVENUE REQUIREMENT (K$/YR) | 13440. | 19758. | -6318. |

## TABLE A-8. SUMMARY OF COAL-CLEANING PERFORMANCE DATA AND CHANGES IN FGD PERFORMANCE DATA AS A RESULT OF COAL CLEANING

| | | | | | Clean coal | | | | Reduction in FGD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | Coal | Specific gravity of coal, clean | Emission standard | Raw coal, lb $SO_2$/MBtu | % $H_2O$, total | % wt recovery, dry | % Btu recovery | Lb $SO_2$/MBtu | Flue gas bypass, % increase | lb/hr $SO_2$ removed, decrease | Reheat, kBtu/hr decrease |
| 1 | ILL6 | 1.40 | 79 NSPS | 8.97 | 6.93 | 56.33 | 77.52 | 3.86 | 22.77 | 45,263 | 111,600 |
| 2 | ILL6 | 1.40 | 0.6 SIP | 8.97 | 6.93 | 56.33 | 77.52 | 3.86 | 6.42 | 43,254 | 39,265 |
| 3 | ILL6 | 1.40 | 1.2 SIP | 8.97 | 6.93 | 56.33 | 77.52 | 3.86 | 21.70 | 43,257 | 105,851 |
| 4 | ILL6 | 1.40 | 2.0 SIP | 8.97 | 6.93 | 56.33 | 77.52 | 3.86 | 36.16 | 43,263 | 0 |
| 5 | ILL6 | 1.40 | 4.0 SIP | 8.97 | 6.93 | 56.33 | 77.52 | 3.86 | 58.03 | 39,127 | 0 |
| 6 | ILL6 | 1.50 | 79 NSPS | 8.97 | 6.63 | 65.17 | 88.25 | 4.18 | 16.10 | 41,322 | 81,905 |
| 7 | ILL6 | 1.50 | 0.6 SIP | 8.97 | 6.63 | 65.17 | 88.25 | 4.18 | 4.97 | 40,561 | 32,615 |
| 8 | ILL6 | 1.50 | 1.2 SIP | 8.97 | 6.63 | 65.17 | 88.25 | 4.18 | 18.80 | 40,564 | 92,865 |
| 9 | ILL6 | 1.50 | 2.0 SIP | 8.97 | 6.63 | 65.17 | 88.25 | 4.18 | 31.33 | 40,569 | 0 |
| 10 | ILL6 | 1.50 | 4.0 SIP | 8.97 | 6.63 | 65.17 | 88.25 | 4.18 | 58.03 | 39,127 | 0 |
| 11 | ILL6 | 1.60 | 70 NSPS | 8.97 | 6.54 | 68.25 | 91.59 | 4.38 | 13.74 | 39,228 | 71,377 |
| 12 | ILL6 | 1.60 | 0.6 SIP | 8.97 | 6.54 | 68.25 | 91.59 | 4.38 | 4.14 | 38,795 | 28,820 |
| 13 | ILL6 | 1.60 | 1.2 SIP | 8.97 | 6.54 | 68.25 | 91.59 | 4.38 | 17.13 | 38,799 | 85,413 |
| 14 | ILL6 | 1.60 | 2.0 SIP | 8.97 | 6.54 | 68.25 | 91.59 | 4.38 | 28.55 | 38,805 | 0 |
| 15 | ILL6 | 1.60 | 4.0 SIP | 8.97 | 6.54 | 68.25 | 91.59 | 4.38 | 57.09 | 38,818 | 0 |
| 16 | ILL6 | 1.80 | 79 NSPS | 8.97 | 6.38 | 73.36 | 95.87 | 5.08 | 9.11 | 32,923 | 50,666 |
| 17 | ILL6 | 1.80 | 0.6 SIP | 8.97 | 6.38 | 73.36 | 95.87 | 5.08 | 1.84 | 32,877 | 18,395 |
| 18 | ILL6 | 1.80 | 1.2 SIP | 8.97 | 6.38 | 73.36 | 95.87 | 5.08 | 12.53 | 32,882 | 64,897 |
| 19 | ILL6 | 1.80 | 2.0 SIP | 8.97 | 6.38 | 73.36 | 95.87 | 5.08 | 20.88 | 32,890 | 0 |
| 20 | ILL6 | 1.80 | 4.0 SIP | 8.97 | 6.38 | 73.36 | 95.87 | 5.08 | 41.77 | 32,908 | 0 |
| 21 | PITT | 1.40 | 79 NSPS | 6.05 | 8.10 | 73.14 | 81.90 | 3.79 | 10.76 | 20,147 | 53,748 |
| 22 | PITT | 1.40 | 0.6 SIP | 6.05 | 8.10 | 73.14 | 81.90 | 3.79 | 6.77 | 19,053 | 36,158 |
| 23 | PITT | 1.40 | 1.2 SIP | 6.05 | 8.10 | 73.14 | 81.90 | 3.79 | 14.49 | 19,070 | 68,579 |
| 24 | PITT | 1.40 | 2.0 SIP | 6.05 | 8.10 | 73.14 | 81.90 | 3.79 | 24.15 | 19,094 | 0 |
| 25 | PITT | 1.40 | 4.0 SIP | 6.05 | 8.10 | 73.14 | 81.90 | 3.79 | 31.68 | 14,407 | 0 |
| 26 | PITT | 1.50 | 79 NSPS | 6.05 | 7.86 | 83.10 | 91.84 | 4.18 | 6.28 | 16,091 | 33,898 |
| 27 | PITT | 1.50 | 0.6 SIP | 6.05 | 7.86 | 83.10 | 91.84 | 4.18 | 4.95 | 15,720 | 28,061 |
| 28 | PITT | 1.50 | 1.2 SIP | 6.05 | 7.86 | 83.10 | 91.84 | 4.18 | 10.85 | 15,737 | 52,450 |
| 29 | PITT | 1.50 | 2.0 SIP | 6.05 | 7.86 | 83.10 | 91.84 | 4.18 | 18.08 | 15,760 | 0 |
| 30 | PITT | 1.50 | 4.0 SIP | 6.05 | 7.86 | 83.10 | 91.84 | 4.18 | 31.68 | 14,407 | 0 |
| 31 | PITT | 1.60 | 79 NSPS | 6.05 | 7.77 | 86.46 | 94.76 | 4.37 | 4.90 | 14,300 | 27,811 |
| 32 | PITT | 1.60 | 0.6 SIP | 6.05 | 7.77 | 86.46 | 94.76 | 4.37 | 4.19 | 14,111 | 24,674 |
| 33 | PITT | 1.60 | 1.2 SIP | 6.05 | 7.77 | 86.46 | 94.76 | 4.37 | 9.33 | 14,129 | 45,725 |
| 34 | PITT | 1.60 | 2.0 SIP | 6.05 | 7.77 | 86.46 | 94.76 | 4.37 | 15.55 | 14,153 | 0 |
| 35 | PITT | 1.60 | 4.0 SIP | 6.05 | 7.77 | 86.46 | 94.76 | 4.37 | 31.09 | 14,212 | 0 |
| 36 | PITT | 1.60 | 79 NSPS | 6.05 | 7.67 | 90.60 | 97.36 | 4.68 | 3.31 | 11,525 | 20,728 |
| 37 | PITT | 1.80 | 0.6 SIP | 6.05 | 7.67 | 90.60 | 97.36 | 4.68 | 3.09 | 11,491 | 19,726 |
| 38 | PITT | 1.80 | 1.2 SIP | 6.05 | 7.67 | 90.60 | 97.36 | 4.68 | 7.12 | 11,510 | 35,957 |
| 39 | PITT | 1.80 | 2.0 SIP | 6.05 | 7.67 | 90.60 | 97.36 | 4.68 | 11.86 | 11,536 | 0 |
| 40 | PITT | 1.80 | 4.0 SIP | 6.05 | 7.67 | 90.60 | 97.36 | 4.68 | 23.73 | 11,600 | 0 |

(Continued)

TABLE A-8. (Continued)

| | | | | | Clean coal | | | | Reduction in FGD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | Coal | Specific gravity of coal, clean | Emission standard | Raw coal, lb $SO_2$/MBtu | % $H_2O$, total | % wt recovery, dry | % Btu recovery | Lb $SO_2$/MBtu | Flue gas bypass, % increase | lb/hr $SO_2$ removed, decrease | Reheat, kBtu/hr decrease |
| 41 | UPPR | 1.40 | 79 NSPS | 3.97 | 10.53 | 67.07 | 78.22 | 1.76 | 32.91 | 19,974 | 0 |
| 42 | UPPR | 1.40 | 0.6 SIP | 3.97 | 10.53 | 67.07 | 78.22 | 1.76 | 23.19 | 18,683 | 106,308 |
| 43 | UPPR | 1.40 | 1.2 SIP | 3.97 | 10.53 | 67.07 | 78.22 | 1.76 | 46.38 | 18,699 | 0 |
| 44 | UPPR | 1.40 | 2.0 SIP | 3.97 | 10.53 | 67.07 | 78.22 | 1.76 | 50.99 | 15,227 | 0 |
| 45 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 46 | UPPR | 1.50 | 79 NSPS | 3.97 | 10.11 | 78.05 | 89.38 | 1.93 | 22.52 | 17,673 | 103,341 |
| 47 | UPPR | 1.50 | 0.6 SIP | 3.97 | 10.11 | 78.05 | 89.38 | 1.93 | 19.51 | 17,234 | 90,576 |
| 48 | UPPR | 1.50 | 1.2 SIP | 3.97 | 10.11 | 78.05 | 89.38 | 1.93 | 39.01 | 17,250 | 0 |
| 49 | UPPR | 1.50 | 2.0 SIP | 3.97 | 10.11 | 78.05 | 89.38 | 1.93 | 50.99 | 15,227 | 0 |
| 50 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 51 | UPPR | 1.60 | 79 NSPS | 3.97 | 9.98 | 81.60 | 92.60 | 2.03 | 19.27 | 16,673 | 89,555 |
| 52 | UPPR | 1.60 | 0.6 SIP | 3.97 | 9.98 | 81.60 | 92.60 | 2.03 | 17.76 | 16,442 | 83,136 |
| 53 | UPPR | 1.60 | 1.2 SIP | 3.97 | 9.98 | 81.60 | 92.60 | 2.03 | 35.51 | 16,458 | 0 |
| 54 | UPPR | 1.60 | 2.0 SIP | 3.97 | 9.98 | 81.60 | 92.60 | 2.03 | 50.99 | 15,227 | 0 |
| 55 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 56 | UPPR | 1.80 | 79 NSPS | 3.97 | 9.67 | 88.18 | 97.01 | 2.35 | 12.55 | 13,637 | 61,073 |
| 57 | UPPR | 1.80 | 0.6 SIP | 3.97 | 9.67 | 88.18 | 97.01 | 2.35 | 12.73 | 13,667 | 61,807 |
| 58 | UPPR | 1.80 | 1.2 SIP | 3.97 | 9.67 | 88.18 | 97.01 | 2.35 | 25.46 | 13,685 | 0 |
| 59 | UPPR | 1.80 | 2.0 SIP | 3.97 | 9.67 | 88.18 | 97.01 | 2.35 | 42.43 | 13,708 | 0 |
| 60 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 61 | CKDR | 1.80 | 79 NSPS | 1.45 | 11.17 | 77.66 | 91.46 | 1.17 | 13.81 | 2,815 | 0 |
| 62 | CKDR | 1.40 | 0.6 SIP | 1.45 | 11.17 | 77.66 | 91.46 | 1.17 | 12.16 | 2,379 | 0 |
| 63 | CKDR | 1.40 | 1.2 SIP | 1.45 | 11.17 | 77.66 | 91.46 | 1.17 | 11.60 | 1,268 | 0 |
| 64 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 65 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 66 | CKDR | 1.50 | 79 NSPS | 1.45 | 11.10 | 79.68 | 93.44 | 1.20 | 11.48 | 2,460 | 0 |
| 67 | CKDR | 1.50 | 0.6 SIP | 1.45 | 11.10 | 79.68 | 93.44 | 1.20 | 10.56 | 2,119 | 0 |
| 68 | CKDR | 1.50 | 1.2 SIP | 1.45 | 11.10 | 79.68 | 93.44 | 1.20 | 11.60 | 1,268 | 0 |
| 69 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 70 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 71 | CKDR | 1.60 | 79 NSPS | 1.45 | 11.04 | 81.12 | 94.72 | 1.23 | 9.86 | 2,188 | 0 |
| 72 | CKDR | 1.60 | 0.6 SIP | 1.45 | 11.04 | 81.12 | 94.72 | 1.23 | 9.31 | 1,906 | 0 |
| 73 | CKDR | 1.60 | 1.2 SIP | 1.45 | 11.04 | 81.12 | 94.72 | 1.23 | 11.60 | 1,268 | 0 |
| 74 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 75 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 76 | CKDR | 1.80 | 79 NSPS | 1.45 | 10.96 | 82.95 | 96.10 | 1.25 | 8.28 | 1,915 | 0 |
| 77 | CKDR | 1.80 | 0.6 SIP | 1.45 | 10.96 | 82.95 | 96.10 | 1.25 | 8.13 | 1,695 | 0 |
| 78 | CKDR | 1.80 | 1.2 SIP | 1.45 | 10.96 | 82.95 | 96.10 | 1.25 | 11.60 | 1,268 | 0 |
| 79 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |
| 80 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | |

## TABLE A-9. SUMMARY OF TOTAL CAPITAL INVESTMENT FOR COAL-CLEANING, FGD, AND ECONOMIC BENEFITS

| | | | | Total capital investment, 1982 k$ | | | | |
|---|---|---|---|---|---|---|---|---|
| Case | Coal | Specific gravity of coal cleaning | Emission standard | Coal cleaning A | FGD decrease B | Economic benefits C | Net cost without FGD D[a] | Net cost with FGD E[b] |
| 1 | ILL6 | 1.40 | 79 NSPS | 41,107 | 67,543 | 101,169 | 7,481 | -60,062 |
| 2 | ILL6 | 1.40 | 0.6 SIP | 41,107 | 48,656 | 83,552 | 6,211 | -42,445 |
| 3 | ILL6 | 1.40 | 1.2 SIP | 41,107 | 65,740 | 100,488 | 6,359 | -59,381 |
| 4 | ILL6 | 1.40 | 2.0 SIP | 41,107 | 84,328 | 118,975 | 6,460 | -77,868 |
| 5 | ILL6 | 1.40 | 4.0 SIP | 41,107 | 137,650 | 175,699 | 3,058 | -134,592 |
| 6 | ILL6 | 1.50 | 79 NSPS | 37,069 | 54,346 | 86,224 | 5,191 | -49,155 |
| 7 | ILL6 | 1.50 | 0.6 SIP | 37,069 | 44,552 | 77,356 | 4,265 | -40,287 |
| 8 | ILL6 | 1.50 | 1.2 SIP | 37,069 | 58,610 | 91,334 | 4,345 | -54,265 |
| 9 | ILL6 | 1.50 | 2.0 SIP | 37,069 | 75,852 | 108,540 | 4,381 | -71,471 |
| 10 | ILL6 | 1.50 | 4.0 SIP | 37,069 | 137,650 | 173,534 | 1,185 | -136,465 |
| 11 | ILL6 | 1.60 | 79 NSPS | 35,888 | 53,314 | 84,330 | 4,872 | -48,442 |
| 12 | ILL6 | 1.60 | 0.6 SIP | 35,888 | 42,027 | 73,814 | 4,101 | -37,926 |
| 13 | ILL6 | 1.60 | 1.2 SIP | 35,888 | 54,119 | 85,865 | 4,142 | -49,977 |
| 14 | ILL6 | 1.60 | 2.0 SIP | 35,888 | 70,879 | 102,628 | 4,139 | -66,740 |
| 15 | ILL6 | 1.60 | 4.0 SIP | 35,888 | 118,542 | 150,432 | 3,998 | -114,544 |
| 16 | ILL6 | 1.80 | 79 NSPS | 34,300 | 41,678 | 70,639 | 5,339 | -36,339 |
| 17 | ILL6 | 1.80 | 0.6 SIP | 34,300 | 33,599 | 62,925 | 4,974 | -28,625 |
| 18 | ILL6 | 1.80 | 1.2 SIP | 34,300 | 42,256 | 71,651 | 4,905 | -37,351 |
| 19 | ILL6 | 1.80 | 2.0 SIP | 34,300 | 58,897 | 88,406 | 4,791 | -54,106 |
| 20 | ILL6 | 1.80 | 4.0 SIP | 34,300 | 80,630 | 110,460 | 4,470 | -76,160 |
| 21 | PITT | 1.40 | 79 NSPS | 32,926 | 31,939 | 41,366 | 23,499 | -8,440 |
| 22 | PITT | 1.40 | 0.6 SIP | 32,926 | 26,652 | 36,922 | 22,656 | -3,996 |
| 23 | PITT | 1.40 | 1.2 SIP | 32,926 | 36,024 | 46,442 | 22,508 | -13,516 |
| 24 | PITT | 1.40 | 2.0 SIP | 32,926 | 46,764 | 57,389 | 22,301 | -24,463 |
| 25 | PITT | 1.40 | 4.0 SIP | 32,926 | 87,326 | 101,957 | 18,295 | -69,031 |
| 26 | PITT | 1.50 | 79 NSPS | 29,486 | 23,260 | 31,388 | 21,358 | -1,902 |
| 27 | PITT | 1.50 | 0.6 SIP | 29,486 | 21,519 | 30,157 | 20,848 | -671 |
| 28 | PITT | 1.50 | 1.2 SIP | 29,486 | 27,102 | 35,977 | 20,611 | -6,491 |
| 29 | PITT | 1.50 | 2.0 SIP | 29,486 | 36,481 | 45,651 | 20,316 | -16,165 |
| 30 | PITT | 1.50 | 4.0 SIP | 29,486 | 87,326 | 100,232 | 16,580 | -70,746 |
| 31 | PITT | 1.60 | 79 NSPS | 28,452 | 20,165 | 27,287 | 21,330 | 1,165 |
| 32 | PITT | 1.60 | 0.6 SIP | 28,452 | 19,252 | 26,757 | 20,947 | 1,695 |
| 33 | PITT | 1.60 | 1.2 SIP | 28,452 | 23,418 | 31,197 | 20,673 | -2,745 |
| 34 | PITT | 1.60 | 2.0 SIP | 28,452 | 31,928 | 40,039 | 20,341 | -11,587 |
| 35 | PITT | 1.60 | 4.0 SIP | 28,452 | 69,656 | 78,453 | 19,655 | -50,001 |
| 36 | PITT | 1.80 | 79 NSPS | 27,302 | 15,411 | 19,799 | 22,914 | 7,503 |
| 37 | PITT | 1.80 | 0.6 SIP | 27,302 | 15,139 | 19,742 | 22,699 | 7,560 |
| 38 | PITT | 1.80 | 1.2 SIP | 27,302 | 17,557 | 22,489 | 22,370 | 4,813 |
| 39 | PITT | 1.80 | 2.0 SIP | 27,302 | 26,383 | 31,701 | 21,984 | -4,399 |
| 40 | PITT | 1.80 | 4.0 SIP | 27,302 | 48,818 | 54,908 | 21,212 | -27,606 |

(Continued)

## TABLE A-9. (Continued)

| | | | | Total capital investment, 1982 k$ | | | | |
|---|---|---|---|---|---|---|---|---|
| Case | Coal | Specific gravity of coal cleaning | Emission standard | Coal cleaning A | FGD decrease B | Economic benefits C | Net cost without FGD D[a] | Net cost with FGD E[b] |
| 41 | UPPR | 1.40 | 79 NSPS | 34,648 | 65,838 | 86,061 | 14,425 | -51,413 |
| 42 | UPPR | 1.40 | 0.6 SIP | 34,648 | 55,851 | 73,548 | 16,951 | -38,900 |
| 43 | UPPR | 1.40 | 1.2 SIP | 34,648 | 72,410 | 90,326 | 16,732 | -55,678 |
| 44 | UPPR | 1.40 | 2.0 SIP | 34,648 | 104,356 | 126,877 | 12,127 | -92,229 |
| 45 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 46 | UPPR | 1.50 | 79 NSPS | 30,724 | 52,728 | 67,086 | 16,366 | -36,362 |
| 47 | UPPR | 1.50 | 0.6 SIP | 30,724 | 46,104 | 60,470 | 16,358 | -29,746 |
| 48 | UPPR | 1.50 | 1.2 SIP | 30,724 | 62,642 | 77,321 | 16,045 | -46,597 |
| 49 | UPPR | 1.50 | 2.0 SIP | 30,724 | 104,356 | 123,372 | 11,708 | -92,648 |
| 50 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 51 | UPPR | 1.60 | 79 NSPS | 29,614 | 45,030 | 57,878 | 16,766 | -28,264 |
| 52 | UPPR | 1.60 | 0.6 SIP | 29,614 | 42,585 | 55,366 | 16,833 | -25,752 |
| 53 | UPPR | 1.60 | 1.2 SIP | 29,614 | 60,334 | 73,473 | 16,475 | -43,859 |
| 54 | UPPR | 1.60 | 2.0 SIP | 29,614 | 104,356 | 121,707 | 12,263 | -92,093 |
| 55 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 56 | UPPR | 1.80 | 79 NSPS | 27,839 | 31,310 | 39,247 | 19,902 | -11,408 |
| 57 | UPPR | 1.80 | 0.6 SIP | 27,839 | 31,596 | 39,358 | 20,077 | -11,519 |
| 58 | UPPR | 1.80 | 1.2 SIP | 27,839 | 48,253 | 56,503 | 19,589 | -28,664 |
| 59 | UPPR | 1.80 | 2.0 SIP | 27,839 | 67,989 | 76,837 | 18,991 | -48,998 |
| 60 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 61 | CEDR | 1.40 | 79 NSPS | 30,879 | 22,877 | 88,966 | -35,210 | -58,087 |
| 62 | CEDR | 1.40 | 0.6 SIP | 30,879 | 13,225 | 76,387 | -32,283 | -45,508 |
| 63 | CEDR | 1.40 | 1.2 SIP | 30,879 | 41,942 | 117,431 | -44,610 | -86,552 |
| 64 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 65 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 66 | CEDR | 1.50 | 79 NSPS | 30,217 | 20,461 | 84,800 | -34,122 | -54,583 |
| 67 | CEDR | 1.50 | 0.6 SIP | 30,217 | 11,382 | 72,693 | -31,094 | -42,476 |
| 68 | CEDR | 1.50 | 1.2 SIP | 30,217 | 41,942 | 115,440 | -43,281 | -85,223 |
| 69 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 70 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 71 | CEDR | 1.60 | 79 NSPS | 29,769 | 17,831 | 80,384 | -32,784 | -50,615 |
| 72 | CEDR | 1.60 | 0.6 SIP | 29,769 | 9,941 | 69,411 | -29,701 | -39,642 |
| 73 | CEDR | 1.60 | 1.2 SIP | 29,769 | 41,942 | 113,493 | -41,782 | -83,724 |
| 74 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 75 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 76 | CEDR | 1.80 | 79 NSPS | 29,254 | 16,166 | 75,529 | -30,109 | -46,275 |
| 77 | CEDR | 1.80 | 0.6 SIP | 29,254 | 8,570 | 64,821 | -26,997 | -35,567 |
| 78 | CEDR | 1.80 | 1.2 SIP | 29,254 | 41,942 | 110,179 | -38,983 | -80,925 |
| 79 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |
| 80 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | |

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a. D = C - A.

b. E = C - B - A.

## TABLE A-10. SUMMARY OF ANNUAL REVENUE REQUIREMENTS FOR COAL-CLEANING, FGD, AND ECONOMIC BENEFITS

| | | | | First-year annual revenue requirements, 1984 k$ | | | | | Levelized annual revenue requirements | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | Coal | Specific gravity of coal clean | Emission standard | Coal clean A | FGD decrease B | Economic benefits C | Net cost without FGD Da | Net cost with FGD Db | Coal clean A | FGD decrease B | Economic benefits C | Net cost without FGD Da | Net cost with FGD Db |
| 1 | ILL6 | 1.40 | 79 NSPS | 12,297 | 18,812 | 63,416 | -32,307 | -51,119 | 17,838 | 26,629 | 119,602 | -75,135 | -101,764 |
| 2 | ILL6 | 1.40 | 0.6 SIP | 12,297 | 12,906 | 59,066 | -33,863 | -46,769 | 17,838 | 18,053 | 111,398 | -75,507 | -93,560 |
| 3 | ILL6 | 1.40 | 1.2 SIP | 12,297 | 18,258 | 63,187 | -32,632 | -50,890 | 17,838 | 25,864 | 119,170 | -75,468 | -101,332 |
| 4 | ILL6 | 1.40 | 2.0 SIP | 12,297 | 21,992 | 65,627 | -31,338 | -53,330 | 17,838 | 30,497 | 123,773 | -75,438 | -105,935 |
| 5 | ILL6 | 1.40 | 4.0 SIP | 12,297 | 32,727 | 73,222 | -28,198 | -60,925 | 17,838 | 43,835 | 138,097 | -76,424 | -120,259 |
| 6 | ILL6 | 1.50 | 79 NSPS | 11,261 | 15,131 | 67,487 | -41,095 | -56,226 | 16,410 | 21,389 | 127,281 | -89,482 | -110,871 |
| 7 | ILL6 | 1.50 | 0.6 SIP | 11,261 | 11,779 | 65,013 | -41,973 | -53,752 | 16,410 | 16,450 | 122,615 | -89,755 | -106,205 |
| 8 | ILL6 | 1.50 | 1.2 SIP | 11,261 | 16,276 | 68,535 | -40,998 | -57,274 | 16,410 | 23,116 | 129,257 | -89,731 | -112,847 |
| 9 | ILL6 | 1.50 | 2.0 SIP | 11,261 | 19,895 | 70,934 | -39,778 | -59,673 | 16,410 | 27,651 | 133,781 | -89,720 | -117,371 |
| 10 | ILL6 | 1.50 | 4.0 SIP | 11,261 | 32,727 | 80,008 | -36,020 | -68,747 | 16,410 | 43,835 | 150,895 | -90,650 | -134,485 |
| 11 | ILL6 | 1.60 | 79 NSPS | 10,959 | 14,572 | 68,370 | -42,839 | -57,411 | 15,994 | 20,538 | 128,945 | -92,413 | -112,951 |
| 12 | ILL6 | 1.60 | 0.6 SIP | 10,959 | 11,088 | 65,807 | -43,760 | -54,848 | 15,994 | 15,479 | 124,113 | -92,640 | -108,119 |
| 13 | ILL6 | 1.60 | 1.2 SIP | 10,959 | 15,077 | 68,917 | -42,881 | -57,958 | 15,994 | 21,355 | 129,977 | -92,628 | -113,983 |
| 14 | ILL6 | 1.60 | 2.0 SIP | 10,959 | 18,703 | 71,390 | -41,728 | -60,431 | 15,994 | 26,020 | 134,642 | -92,628 | -118,648 |
| 15 | ILL6 | 1.60 | 4.0 SIP | 10,959 | 28,411 | 77,884 | -38,514 | -66,925 | 15,994 | 38,226 | 146,889 | -92,669 | -130,895 |
| 16 | ILL6 | 1.60 | 79 NSPS | 10,557 | 11,364 | 65,844 | -43,923 | -55,287 | 15,443 | 15,927 | 124,182 | -92,812 | -108,739 |
| 17 | ILL6 | 1.80 | 0.6 SIP | 10,557 | 8,832 | 63,999 | -44,610 | -53,442 | 15,443 | 12,340 | 120,702 | -92,919 | -105,259 |
| 18 | ILL6 | 1.80 | 1.2 SIP | 10,557 | 11,843 | 66,380 | -43,980 | -55,823 | 15,443 | 16,812 | 125,194 | -92,939 | -109,751 |
| 19 | ILL6 | 1.80 | 2.0 SIP | 10,557 | 15,746 | 69,180 | -42,877 | -58,623 | 15,443 | 22,058 | 130,473 | -92,972 | -115,030 |
| 20 | ILL6 | 1.80 | 4.0 SIP | 10,557 | 19,589 | 71,559 | -41,413 | -61,002 | 15,443 | 26,453 | 134,961 | -93,065 | -119,518 |
| 21 | PITT | 1.40 | 79 NSPS | 10,216 | 8,839 | 7,475 | 11,580 | 2,741 | 14,979 | 12,495 | 14,099 | 13,375 | 880 |
| 22 | PITT | 1.40 | 06 SIP | 10,216 | 7,233 | 6,400 | 11,049 | 3,816 | 14,979 | 10,217 | 12,070 | 13,126 | 2,909 |
| 23 | PITT | 1.40 | 1.2 SIP | 10,216 | 10,091 | 8,638 | 11,669 | 1,578 | 14,979 | 14,396 | 16,291 | 13,084 | -1,312 |
| 24 | PITT | 1.40 | 2.0 SIP | 10,216 | 11,507 | 9,294 | 12,429 | 922 | 14,979 | 15,575 | 17,529 | 13,025 | -2,550 |
| 25 | PITT | 1.40 | 4.0 SIP | 10,216 | 20,309 | 15,935 | 14,590 | -5,719 | 14,979 | 26,937 | 30,054 | 11,862 | -15,075 |
| 26 | PITT | 1.50 | 79 NSPS | 9,348 | 6,362 | 10,053 | 5,657 | -705 | 13,790 | 9,019 | 18,959 | 3,850 | -5,169 |
| 27 | PITT | 1.50 | 0.6 SIP | 9,348 | 5,831 | 9,679 | 5,500 | -331 | 13,790 | 8,163 | 18,255 | 3,698 | -4,465 |
| 28 | PITT | 1.50 | 1.2 SIP | 9,348 | 7,630 | 11,158 | 5,820 | -1,810 | 13,790 | 10,884 | 21,044 | 3,630 | -7,254 |
| 29 | PITT | 1.50 | 2.0 SIP | 9,348 | 8,974 | 11,881 | 6,441 | -2,533 | 13,790 | 12,163 | 22,408 | 3,545 | -8,618 |
| 30 | PITT | 1.50 | 4.0 SIP | 9,348 | 20,309 | 20,290 | 9,367 | -10,942 | 13,790 | 26,937 | 38,267 | 2,460 | -24,477 |
| 31 | PITT | 1.60 | 79 NSPS | 9,091 | 5,491 | 10,020 | 4,562 | -929 | 13,440 | 7,764 | 18,898 | 2,306 | -5,458 |
| 32 | PITT | 1.60 | 0.6 SIP | 9,091 | 5,211 | 9,851 | 4,451 | -760 | 13,440 | 7,330 | 18,579 | 2,191 | -5,139 |
| 33 | PITT | 1.60 | 1.2 SIP | 9,091 | 6,626 | 11,013 | 4,704 | -1,922 | 13,440 | 9,443 | 20,771 | 2,112 | -7,331 |
| 34 | PITT | 1.60 | 2.0 SIP | 9,091 | 7,883 | 11,727 | 5,247 | -2,636 | 13,440 | 10,694 | 22,118 | 2,016 | -8,678 |
| 35 | PITT | 1.60 | 4.0 SIP | 9,091 | 16,329 | 17,689 | 7,731 | -8,598 | 13,440 | 21,739 | 33,361 | 1,818 | -19,921 |
| 36 | PITT | 1.80 | 79 NSPS | 8,808 | 4,207 | 8,392 | 4,623 | 416 | 13,056 | 5,966 | 15,827 | 3,195 | -2,771 |
| 37 | PITT | 1.80 | 0.6 SIP | 8,808 | 4,123 | 8,353 | 4,578 | 455 | 13,056 | 5,825 | 15,753 | 3,128 | -2,697 |
| 38 | PITT | 1.80 | 1.2 SIP | 8,808 | 5,049 | 9,175 | 4,682 | -367 | 13,056 | 7,281 | 17,304 | 3,033 | -4,248 |
| 39 | PITT | 1.80 | 2.0 SIP | 8,808 | 6,516 | 10,081 | 5,243 | -1,273 | 13,056 | 8,879 | 19,013 | 2,922 | -5,957 |
| 40 | PITT | 1.80 | 4.0 SIP | 8,808 | 11,496 | 13,644 | 6,660 | -4,836 | 13,056 | 15,376 | 25,733 | 2,699 | -12,677 |

(Continued)

TABLE A-10. (Continued)

| | | | | First-year annual revenue requirements, 1984 k$ | | | | | Levelized annual revenue requirements | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | Coal | Specific gravity of coal clean | Emission standard | Coal clean A | FGD decrease B | Economic benefits C | Net cost without FGD D[a] | Net cost with FGD E[b] | Coal clean A | FGD decrease B | Economic benefits C | Net cost without FGD D[a] | Net cost with FGD E[b] |
| 41 | UPPR | 1.40 | 79 NSPS | 10,674 | 17,677 | 14,474 | 13,877 | -3,800 | 15,619 | 24,778 | 27,299 | 13,098 | -11,680 |
| 42 | UPPR | 1.40 | 0.6 SIP | 10,674 | 15,244 | 12,288 | 13,630 | -1,614 | 15,619 | 21,410 | 23,176 | 13,853 | -7,557 |
| 43 | UPPR | 1.40 | 1.2 SIP | 10,674 | 17,891 | 13,878 | 14,687 | -3,204 | 15,619 | 24,344 | 26,174 | 13,789 | -10,555 |
| 44 | UPPR | 1.40 | 2.0 SIP | 10,674 | 24,608 | 19,097 | 16,185 | -8,423 | 15,619 | 32,840 | 36,016 | 12,443 | -20,397 |
| 45 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 46 | UPPR | 1.50 | 79 NSPS | 9,674 | 14,483 | 17,274 | 6,883 | -7,600 | 14,244 | 20,451 | 32,578 | 2,117 | -18,334 |
| 47 | UPPR | 1.50 | 0.6 SIP | 9,674 | 12,744 | 15,964 | 6,454 | -6,290 | 14,244 | 17,977 | 30,108 | 2,113 | -15,864 |
| 48 | UPPR | 1.50 | 1.2 SIP | 9,674 | 15,561 | 17,725 | 7,510 | -8,051 | 14,244 | 21,208 | 33,430 | 2,022 | -19,186 |
| 49 | UPPR | 1.50 | 2.0 SIP | 9,674 | 24,608 | 24,565 | 9,717 | -14,891 | 14,244 | 32,840 | 46,330 | 754 | -32,086 |
| 50 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 51 | UPPR | 1.60 | 79 NSPS | 9,394 | 12,475 | 16,711 | 5,158 | -7,317 | 13,860 | 17,619 | 31,518 | -39 | -17,658 |
| 52 | UPPR | 1.60 | 0.6 SIP | 9,394 | 11,732 | 16,140 | 4,986 | -6,746 | 13,860 | 16,560 | 30,441 | -21 | -16,581 |
| 53 | UPPR | 1.60 | 1.2 SIP | 9,394 | 14,946 | 18,215 | 6,125 | -8,821 | 13,860 | 20,369 | 34,354 | -125 | -20,494 |
| 54 | UPPR | 1.60 | 2.0 SIP | 9,394 | 24,608 | 25,481 | 8,521 | -16,087 | 13,860 | 32,840 | 48,057 | -1,357 | -34,197 |
| 55 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 56 | UPPR | 1.80 | 79 NSPS | 8,955 | 8,700 | 13,383 | 4,272 | -4,428 | 13,264 | 12,303 | 25,239 | 328 | -11,975 |
| 57 | UPPR | 1.80 | 0.6 SIP | 8,955 | 8,781 | 13,433 | 4,303 | -4,478 | 13,264 | 12,445 | 25,334 | 375 | -12,070 |
| 58 | UPPR | 1.80 | 1.2 SIP | 8,955 | 11,962 | 15,548 | 5,369 | -6,593 | 13,264 | 16,293 | 29,324 | 233 | -16,060 |
| 59 | UPPR | 1.80 | 2.0 SIP | 8,955 | 16,244 | 18,558 | 6,641 | -9,603 | 13,264 | 21,794 | 35,000 | 58 | -21,736 |
| 60 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 61 | CEDR | 1.40 | 79 NSPS | 9,734 | 5,881 | 17,720 | -2,105 | -7,986 | 14,337 | 8,163 | 33,420 | -10,920 | -19,083 |
| 62 | CEDR | 1.40 | 0.6 SIP | 9,734 | 3,288 | 15,352 | -2,330 | -5,618 | 14,337 | 4,544 | 28,954 | -10,073 | -14,617 |
| 63 | CEDR | 1.40 | 1.2 SIP | 9,734 | 9,696 | 21,615 | -2,185 | -11,881 | 14,337 | 12,866 | 40,766 | -13,563 | -26,429 |
| 64 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 65 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 66 | CEDR | 1.50 | 79 NSPS | 9,567 | 5,288 | 17,828 | -2,973 | -8,261 | 14,108 | 7,308 | 33,623 | -12,207 | -19,515 |
| 67 | CEDR | 1.50 | 0.6 SIP | 9,567 | 2,786 | 15,489 | -3,136 | -5,922 | 14,108 | 3,773 | 29,213 | -11,332 | -15,105 |
| 68 | CEDR | 1.50 | 1.2 SIP | 9,567 | 9,696 | 22,140 | -2,877 | -12,573 | 14,108 | 12,866 | 41,756 | -14,782 | -27,640 |
| 69 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 70 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 71 | CEDR | 1.60 | 79 NSPS | 9,454 | 4,674 | 17,553 | -3,425 | -8,099 | 13,953 | 6,521 | 33,105 | -12,631 | -19,152 |
| 72 | CEDR | 1.60 | 0.6 SIP | 9,454 | 2,436 | 15,406 | -3,516 | -5,952 | 13,953 | 3,361 | 29,055 | -11,741 | -15,102 |
| 73 | CEDR | 1.60 | 1.2 SIP | 9,454 | 9,696 | 22,259 | -3,109 | -12,805 | 13,953 | 12,866 | 41,981 | -15,162 | -28,028 |
| 74 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 75 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 76 | CEDR | 1.80 | 79 NSPS | 9,325 | 4,266 | 17,053 | -3,462 | -7,728 | 13,777 | 5,976 | 32,162 | -12,409 | -18,385 |
| 77 | CEDR | 1.80 | 0.6 SIP | 9,325 | 2,103 | 14,924 | -3,496 | -5,599 | 13,777 | 2,859 | 28,147 | -11,511 | -14,370 |
| 78 | CEDR | 1.80 | 1.2 SIP | 9,325 | 9,696 | 22,030 | -3,009 | -12,705 | 13,777 | 12,866 | 41,549 | -14,906 | -27,772 |
| 79 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |
| 80 | | ***** NO SULFUR REMOVAL NEEDED ***** | | | | | | | | | | | |

a. D = A - C.
b. E = A - B - C.